CORRELATION & BIOSTRATIGRAPHY OF SURFACE AND SHALLOW SUBSURFACE SECTIONS OF THE BARNETT SHALE, LLANO UPLIFT, SOUTH-CENTRAL, TEXAS

By

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New Delhi, India

2003

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
July, 2007

CORRELATION & BIOSTRATIGRAPHY OF SURFACE

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THE BARNETT SHALE, LLANO UPLIFT,

SOUTH-CENTRAL, TEXAS

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ACKNOWLEDGEMENT

I wish to acknowledge all the people that helped to bring this endeavor to a conclusion. My most sincere acknowledgements are due to Dr. Jim Puckette for providing his supervision, encouragement, emotional support and expert suggestions throughout the preparation of this report. I would also like to thank my committee members Dr. Darwin Boardman and Dr. Anna Cruse for their guidance and constructive criticism. I would like express my gratitude to Dr. Boardman for helping me identify conodonts and establish the biostratigraphy.

I would like to thank the Texas Bureau of Economic Geology and Dr. Steve Ruppel in particular to providing access to the core from McCulloch County, Texas. I would like to express my sincere appreciation to Devon Energy and Dr. Bill Coffey for supporting the research. This project would not have been possible without the financial backing of Devon Energy. Acknowledgements are also due to Andy Rihn, Eric Gerding, and Patrick Kamman for their help in field work at San Saba County, Texas.

Finally I would like to extend my love and thanks to my friends and family members back home who have always been there with me and have helped me achieve my goals and have made my dreams come true.

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CHAPTER I

INTRODUCTION

Unconventional natural-gas reservoirs are an increasing focus of activity in several United States basins. The recent emergence of the Barnett Formation as a target for unconventional gas production has sparked renewed interest in the geological character of the Mississippian succession in the subsurface of Texas. For more than a century, Mississippian aged rocks have been known and studied in Texas (Gabb, 1862; Shumard, 1863). Plummer and Moore (1922) named the Barnett Shale from an outcrop in San Saba County, Texas. Despite this considerable study, and in part as a consequence of it, many questions remain unanswered. The Barnett Shale in the Fort Worth Basin is a thick shale interval that cannot be subdivided with confidence using lithology. In addition, no biostratigraphic framework exists for the Barnett Shale in the subsurface. The objectives of this thesis are to examine the outcrop section of the Barnett in eastern San Saba, County and shallow core from McCulloch County, Texas to establish:

1) Stratigraphic framework based on lithology & biostratigraphy, and

2) Depositional style and paleogeographic history for the Barnett Shale interval.

In the study area, the Barnett Formation rests disconformably on the Early Mississippian Chappel Limestone and is overlain by the Lower Pennsylvanian Marble Falls Limestone. An apparently complete stratigraphic section of the Barnett Shale is exposed in a roadcut and adjoining shale quarry 2.5 miles southeast of San Saba, Texas on Texas County Road 1031. This outcrop, which is also known as the Type Chappel locality, is believed to be the best exposed Barnett section in Texas.

The Barnett Shale is an organic-rich, petroliferous black shale of late Mississippian (Meramacian – Chesterian) age that is recognized as a probable source rock for hydrocarbons throughout north-central Texas (Montgomery et al., 2005). It serves as a source, seal, and reservoir for a world-class unconventional natural-gas accumulation in the Fort Worth Basin of north-central Texas. Barnett Shale deposition and current distribution can be explained within the context of Paleozoic tectonism in the southern Mid-continent region. The Barnett Shale originated as a normal marine shelf deposit on the western flank of a basin formed by the subsiding southern Oklahoma aulocogen.

The Barnett Shale outcrop along the southern margin of the Fort-Worth Basin on the north flank of the Llano Uplift consists of siliceous shale, limestone, and minor dolomite. In general, the formation is relatively rich in silica (35-50 %, by volume) and poor in clay minerals (<35%). On Llano Uplift, in Llano, Lampasas, and San Saba counties, the Barnett Shale is 30-50 ft (9-15 m) thick and highly petroliferous (Cheney, 1940; Plummer, 1950). The organic content is highest in clay rich intervals (3-13%; average ~ 3.2% by weight in cuttings) (Jarvie, 2003) and clay content is also high in silica-rich intervals, which comprises the primary producing facies of the Barnett Shale. The Barnett Shale is distinct on wireline logs due to its relatively high gamma ray readings and high resistivity (Montgomery, et al., 2005).

Prior to the 1980s, the Barnett Shale was not considered a target for oil & gas exploration in the Fort Worth Basin. At this time oil & gas drilling focused on

Pennsylvanian clastic reservoirs and, to a lesser extent, Ordovician, Mississippian, and Pennsylvanian carbonates. However wells that penetrated the Barnett recorded gas shows from the shale. In the 1990s, Mitchell Energy initiated the Barnett Shale play, which is interpreted as a continuous-type natural-gas accumulation (Schmoker et al., 1996; Pollastro, 2003). Development has established proven reserves of more than 2.7 tcf of gas in the Fort Worth Basin. Estimates for the total in-place Barnett gas resource are on the order of 200 tcf, with ultimate technically recoverable reserves variably assessed at 3-40 tcf (Schmoker et al., 1996; Jarvie et al., 2004; Pollastro et al., 2004b). Compared with other gas-shale plays, the Barnett Shale is considered unique in several aspects (Montgomery et al., 2005). First, the Barnett produces from greater depths and, therefore at higher pressures than do other gas-shale reservoirs. Second, Barnett gas is entirely thermogenic in origin and, in large areas of the basin, occurs in conjunction with liquid petroleum. Third, the Barnett Shale has undergone a complex, multiphase thermal history, making geochemical considerations central to patterns of productivity. Fourth, natural fractures do not appear essential for production and, in some cases, may even reduce well performance. Overall, these and other factors have presented a set of challenges to geoscientists engaged in reservoir characterization of the Barnett Shale (Montgomery et al., 2005).

This study is designed to establish a stratigraphic framework for the Barnett in the outcrop and shallow subsurface. If adequate core becomes available, the framework should be extended into the Fort Worth Basin, which would provide a sound basis for stratigraphic subdivision in the thick mudrock interval that comprises the Barnett gas rock.

REVIEW OF LITERATURE

There is an extensive history of geologic study of the Llano Uplift and Fort Worth Basin. The first published description of the rocks and fossils of the Llano region were made by Ferdinand Roemer in 1847 (Plummer, 1943). His report was based on observations during extensive travel in Texas with German colonists before and during 1847. Schumard (1863) mentioned the presence of Carboniferous rocks in central Texas in a letter to the St. Louis Academy of Science, which described his work in Burnett County (Kier, 1972).

The first systematic studies of Carboniferous rocks in central Texas were published in the first Annual Report of the fourth Geological Survey of Texas in 1890. In this report, Dumble , State Geologist, proposed the name “Bend series” for Carboniferous shale….. well exposed at McAnnelly’s bend, in San Saba county. Although he collected fossils from these strata, Dumble was uncertain of the age of the rocks and only tentatively placed the “Bend Series” in the “Subcarboniferous.” In the second Annual Report of the Texas Geological Survey, Cummins (1891) described more fully the general geology of central Texas. In this report, Cummins utilized the “Bend Division” and defined a new division, the Strawn, which he stated was deposited unconformably upon the Bend in the “Central Coal Field.” He repeated his assertion that the Bend belongs to the Carboniferous (Kier 1972). Drake (1893), in the Fourth Annual Report of the Texas Geological Survey, briefly redescribed the Bend. He is best remembered, however, for his subdivision of the Strawn into 19 beds (Kier, 1972).

Further work by Hill (1889 and 1901), Paige (1911 and 1912), Udden (in Udden, Baker, and Bose, 1916), Plummer and Moore (1922), and Sellards (in Sellards, Adkins, and Plummer, 1933) produced a change of the Bend from a series to a group and subdivision of the Bend into Chappel, Barnett, Marble Falls, and Smithwick Formations.

Plummer studied the Carboniferous rocks exposed in the Llano area in considerable detail. Plummer's work spanned more than 30 years, and in his publications in 1919, 1945, 1947a, and 1947b, and posthumously in 1950, he greatly revised the stratigraphic subdivisions and nomenclature of the Carboniferous rocks. Plummer studied the Marble Falls Limestone in the greatest detail and proposed several members and published numerous stratigraphic sections. Unfortunately, Plummer did not map these subdivisions and, with few exceptions, no subsequent workers have been able to utilize his classification.

Miller and Youngquist (1948) described cephalopods from the Barnett formation. Miller and Youngquist's (1948) views on the age and correlatives of the Barnett are given in the following statement:

"The collection now available for study indicate that there is only one (cephalopod) faunal zone in the Barnett, but we are not able to ascertain with certainty whether the fauna is upper Visean or Lower Namurian (or both) in age. Furthermore, the cephalopods do not indicate the correlative of the Barnett in the classical Mississippian section of the middle Mississippi valley, for the beds there have yielded too few ammonoids. However, from a study of the cephalopods alone, we can conclude that the Barnett is of approximately the same age as the Caney of Oklahoma, the Moorefield, Ruddell, Batesville, and /or lower Fayetteville of Arkansas, the "Meramec" of Kentucky, the Helms of West Texas, the White Pine of Nevada and south-eastern California, and the goniatite-bearing portions of the Floyd of Georgia."

Plummer and Scott (1937) were of the opinion that the Barnett Formation is Upper Mississippian based on a study of cephalopods. Plummer (1950) correlated the

Barnett with the Moorefield Shale (Moorefield Formation and Ruddell Shale of present usage) and placed both formations in the Chester. His opinion was that:

> "The Barnett faunas correlate with the Moorefield of Arkansas and not with the Fayetteville or Pitkin."

Cloud and Barnes (1946) included in the lower part of the Barnett Formation, beds that Plummer (1950) placed in the Chappel Limestone as the White's Crossing coquina member. Plummer considered these beds to be of Burlington age, whereas Cloud and Barnes considered them to be of Keokuk age. Weller and others (1948) summarized these prevailing opinions as follows:

> "The Barnett shale is similar lithologically and faunally to the lower part of the Caney shale of Oklahoma. Generally, it has been correlated with Chesterian * * * * but its relations to the Ruddell shale of Arkansas seem to be much closer."

Conodonts from the Barnett were studied by Roundy (1926), Cloud and Barnes (1946) and Hass (1953). Until 1953, when Hass came up with his own classification, the United States Geological Survey recognized the conodont classification as proposed by Cloud and Barnes (1946). According to Cloud and Barnes, the Barnett ranged from Keokuk to Ste. Genevieve in age. Plummer (1950) placed the White's Crossing coquina member in the Chappel Limestone (Hass, 1953). Plummer (1950) considered such rocks to be of Burlington age.

Manger et al., (1985) examined biostratigraphy of the Mississippian-Pennsylvanian boundary of the Llano region and concluded that the contact of the Barnett Shale and overlying Marble Falls is a pronounced unconformity corresponding to the Mississippian-Pennsylvanian boundary throughout the Llano Uplift. Manger et al., (1985) showed that Barnett shale yields the same middle Chesterian *Gnathodus bilineatus-G.*

commutatus conodont assemblage at all localities and the initiation of Pennsylvanian deposition was highly diachronous across the region. Manger et al., (1985), reported that the Upper Barnett ammonoid assemblage of *Dombarites, Lusitanites, Paracravenoceras,* and *Eumorphoceras* is typical of the middle Chesterian. On the basis of faunal data, Manger et al., (1985) stated that the top of the Barnett Shale is a biostratigraphically isochronous surface throughout the entire Llano region.

Turner (1957) published an excellent early summary of Paleozoic stratigraphy of the Forth Worth Basin. The U.S. Geological Survey study of the Mississippian section of the United States (Craig and Connor, 1979) included a general analysis of Barnett thickness and facies patterns in the basin. Henry (1982) provided a basic analysis of Barnett and underlying Chappel formations. Gutschick and Sandberg (1983) published a valuable analysis of the middle Osagean (lower Mississippian) section across the United States, primarily on the basis of their work in the western United States. Ruppel (1985) described thickness and facies variations in the Mississippian section in the Palo Duro and Hardeman basins and also published a general stratigraphic model for the Hardeman–Forth Worth Basin areas (Ruppel, 1989).

More recently, Montgomery (2004) and Montgomery et al. (2005) published an extensive summary of the Barnett in the Fort Worth Basin. Boardman et al., (2006), studied the cyclic stratigraphy and conodont biostratigraphy of the Barnett Shale from the type locality of the Chappel Limestone. Loucks & Ruppel (2007) examined several cores of Barnett Shale from the Fort Worth basin and conducted a detailed study on sedimentology, stratigraphy and depositional history of the formation.

STRATIGRAPHY

The generalized stratigraphy of the Llano Uplift and Fort Worth Basin is shown in (Figure 1). In the basin, the subsurface stratigraphic section consists of 4000–5000 ft (1220–1524 m) of Ordovician–Mississippian carbonates and shales, 6000– 7000 ft (1829–2134 m) of Pennsylvanian clastics and carbonates, and in the eastern parts of the basin, a thin veneer of Cretaceous rocks (Flawn et al., 1961; Henry, 1982; Lahti and Huber, 1982; Thompson, 1988). Stratigraphic relations and burial-history reconstructions indicate that a thick (>4000 ft; >1220 m) section of upper Pennsylvanian and possibly Permian strata was eroded prior to the incursion of Early Cretaceous seas (Henry, 1982; Walper, 1982). The basement rocks consist of Precambrian granite and diorite (Pollastro et al., 2007) (Figure 1).

The Barnett Shale unconformably overlies the early to middle Ordovician age Ellenburger Limestone in parts of the Fort Worth Basin and the Mississippian (Osagean) Chappel Formation on the Llano Uplift. Where exposed, the Ellenburger is siliceous and contains chert nodules. The Ellenburger surface is characterized by numerous sinkholes into which overlying strata have collapsed (Schwarz, 1975). Unconformably overlying the Ellenburger are shale and limestone of the Houy, Chappel, and Barnett formations. The Houy Formation consists of the Ives Breccia and the Doublehorn Shale. In the study area, the Houy Formation is represented by the Ives Breccia, which consists of a thin layer (1 foot) of irregularly bedded silica-cemented breccia.

The Chappel Limestone, which is a grain-rich carbonate characterized by disarticulated crinoid fragments (Boardman et al., 2006), ranges from a few inches thick to several feet thick within and adjacent to sinkholes in the Ellenburger. At the Type

Chappel locality and other nearby outcrops, the Chappel is commonly covered with weathered Barnett Shale and the nature of the contact between the Barnett & Chappel is difficult to interpret. Defandorf (1960), Turner (1970), and Kier (1972), believed that they observed interfingering of the Chappel and Barnett (Schwarz, 1975).

The Pennsylvanian (Morrowan) Marble Falls Limestone overlies the Barnett Shale (Figure 1). The nature of the Barnett-Marble Falls contact in the Llano region, central Texas, remains controversial. Lithostratigraphic evidence has been used to support its interpretation as a conformable, intertonguing relationship; whereas biostratigraphic evidence, particularly conodont occurrences, suggests that the boundary is a major regional unconformity (Manger et al., 1985). Henry (1982), concluded that the contact of the Barnett with the overlying Marble Falls Formation is, in most places, definitely conformable and the erosional surface that has been supposed by some to exist at "the top of the Barnett" is in fact an Atokan unconformity that truncates all rock units from the lower Marble Falls down through the Ellenburger, and the Barnett is only locally affected.

The Marble Falls consists of an upper limestone interval and a lower unit of interbedded dark limestone and gray-black shale, sometimes referred to as the Comyn Formation (Kier, 1972). The lower shale section of the lower Marble Falls is commonly used as a marker unit, but it is also commonly mistaken on subsurface well logs for the Barnett Shale (informally referred to by the industry as ''false Barnett''), Pollastro et al., (2007). This shale marker unit or false Barnett Shale in the lower Marble Falls Limestone is shown on the log section from a well in the Fort Worth Basin (Figure 2). In the Fort Worth Basin uppermost Mississippian and lowermost Pennsylvanian rocks appear conformable, but may include disconformities in some areas (e.g., proximal to the Muenster Arch) (Flippin, 1982; Henry, 1982). Pennsylvanian rocks above the Marble Falls generally consist of clastic and mixed carbonate deposits that represent a range of westward-prograding fluvial deltaic environments, and transgressive carbonate bank deposits (Cleaves, 1982; Thompson, 1988).

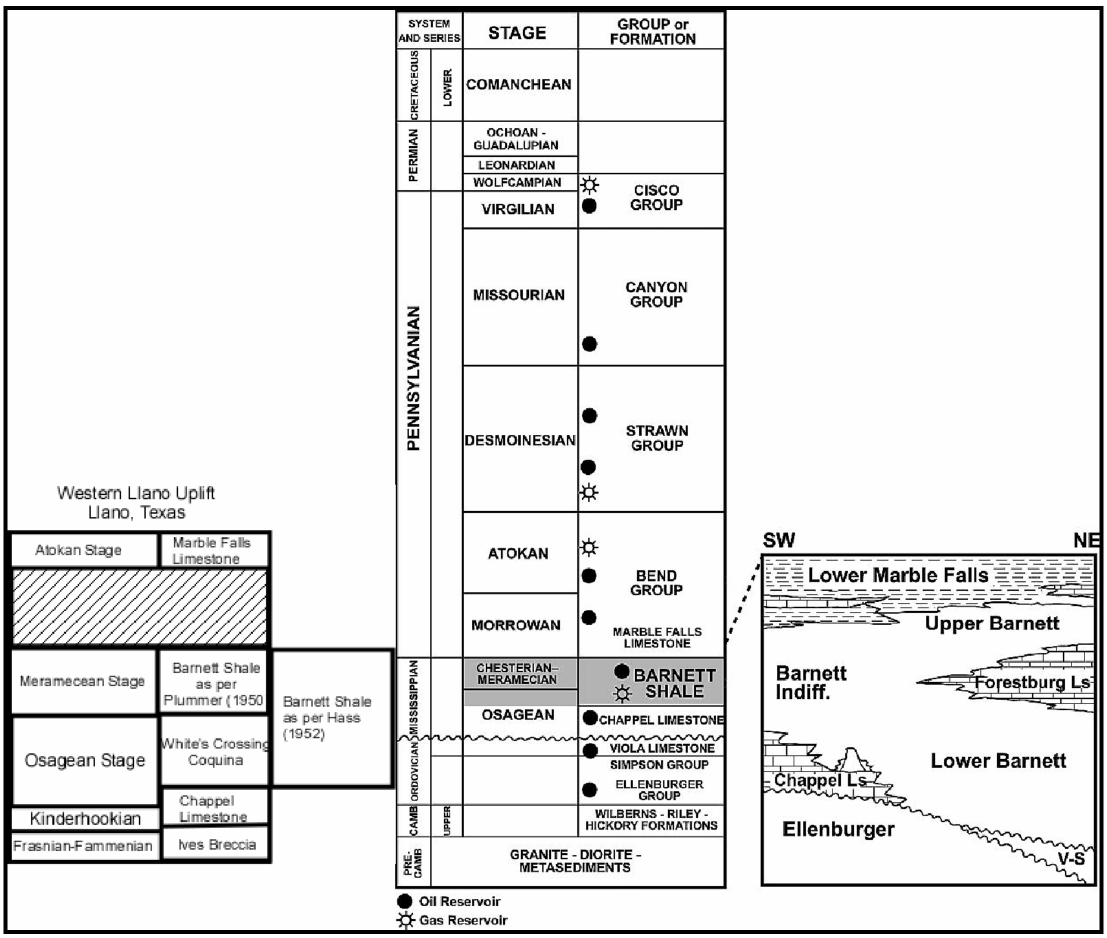


Figure 1. Generalized stratigraphic column of Fort Worth basin and western Llano Uplift. Expanded section shows more detailed interpretation of Mississippian stratigraphy. V-S refers to Viola- Simpson interval (modified after Montgomery, 2005).

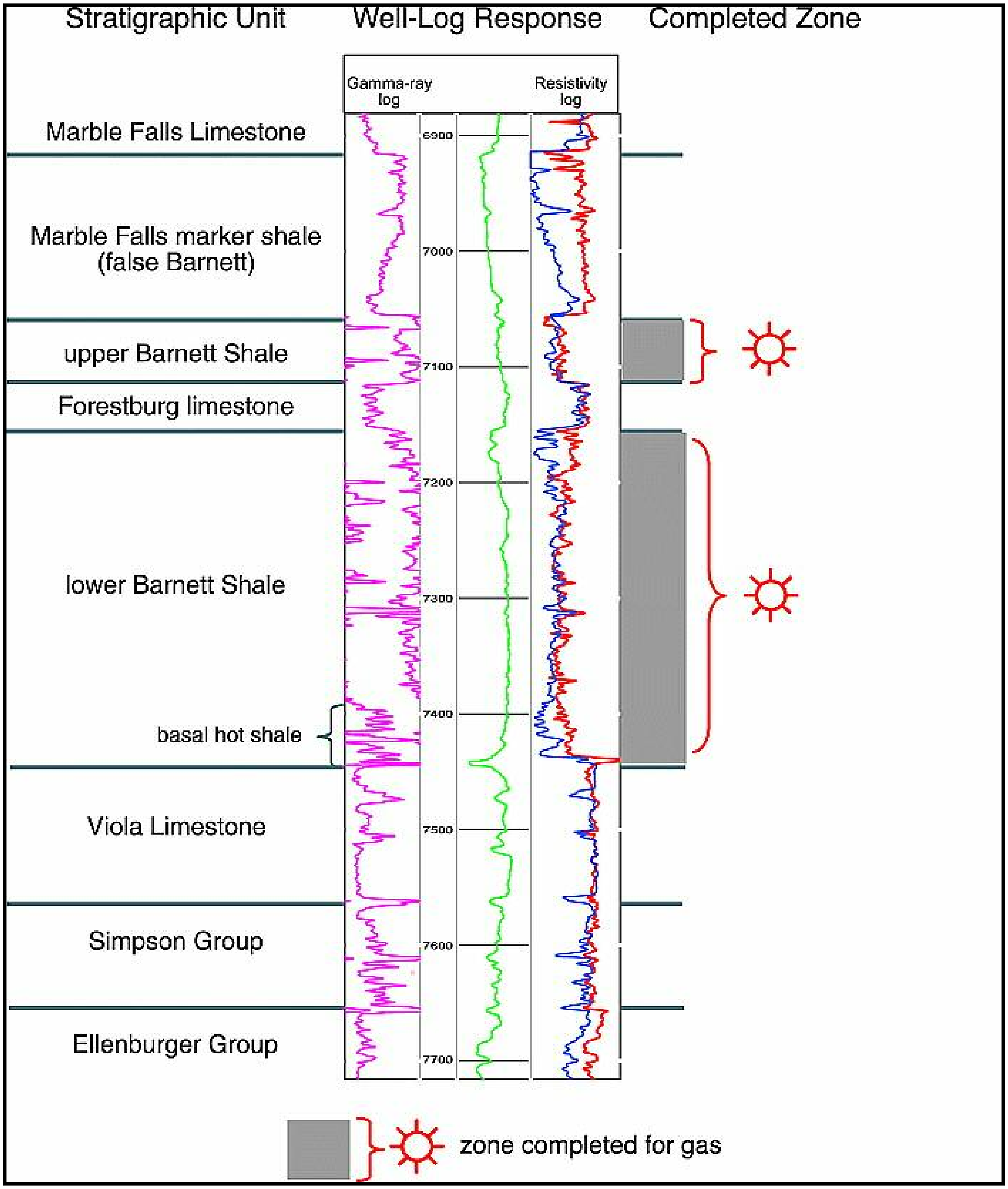


Figure 2. Typical well-log stratigraphic section showing gamma-ray and resistivity logs through the Barnett Shale and overlying and underlying units. Depths are in feet (Pollastro et al., 2007).

CHAPTER II

METHODOLOGY

OBJECTIVE

There is an extensive history of geologic study of the Llano Uplift and Fort Worth Basin. However, despite these studies many questions remain unanswered regarding the subsurface stratigraphy. The Barnett Shale has limited lithologic variability and has no biostratigraphic framework. If a stratigraphic framework is established for the outcrop and shallow subsurface, our understanding of the processes that affected the basinal section will be enhanced.

The overall objective of this study is to construct a stratigraphic framework for the Barnett Shale based on outcrop and shallow core data. A secondary objective is to examine the depositional patterns and establish a generalized depositional model for the Barnett Shale. It is believed that future work can extend this correlation into the deeper part of the basin where stratigraphy is relatively undefined.

Due to the scarcity of outcrops, places to measure sections of the Barnett Shale are few. The thickest exposure of the Barnett Formation is at the type locality of the Chappel Limestone, a road cut and quarry located 2.5 miles southeast of San Saba, Texas (Figure 3). This outcrop contains the Barnett, Chappel, Ives Breccia and Ellenburger and offers good exposure of the contact between these units.

METHODS

The study began in the fall of 2005. The field guide for the local geology of San Saba County by Plummer (1943) was used to locate the outcrop. The field work was done in the month of October, 2005. While working in the field at Type Chappel locality, forty four units were identified, measured and described at the road cut and quarry section of the Barnett, Ellenburger, Ives Breccia and Marble Falls Limestone outcrop.

Weathered and fresh colors for outcrop strata were determined using the standard Geological Society of America (GSA) color chart. Descriptions from the road cut and quarry were combined to create a composite lithologic section (Boardman et al., 2006). Structural dip was measured at 10-15 degrees and true thicknesses were determined in the field by using a Jacob staff. Special attention was paid to the stacking patterns and key sequence stratigraphic surfaces in the section. The outcrop was traversed using a portable spectral gamma-ray scintillometer and magnetic susceptibility meter.

A Barnett Shale core from McCulloch County, Texas was obtained from Texas Bureau of Economic Geology. The cored well, Johansen MC-1, was drilled by Houston Oil & Minerals Corporation. The core was measured, described and examined for subtle changes in composition, mineralogy and bed/laminae thickness, sedimentary structures, macrofossils and key sequence stratigraphic surfaces. Approximately 40 different units were identified on the basis of compositional differences, color and fossils (White's Crossing Limestone to Marble Falls Limestone). The core was surveyed with the magnetic susceptibility meter to develop a data set that would facilitate correlation of core and surface gamma-ray and magnetic-susceptibility signatures.

Forty four outcrop and forty five core samples were collected for lithologic analyses, including x-ray diffractommetry and paleontological analysis. Twenty three thin sections were made from core samples. Thin section microscopy was used to determine and confirm origin of Barnett Shale by estimating percentages of bioclasts, sand and silt. The lithologic and faunal content was analyzed to interpret depositional environments. It was not possible to collect competent samples of Barnett from the Type Chappel locality for thin sections owing to its highly weathered nature.

Shale samples for biostratigraphic analysis were processed with hydrogen peroxide whereas limestone samples were processed with formic acid & water. Five hundred grams (~1.23 lb) of each outcrop and core samples were broken into small pieces before being treated with the required medium for disaggregation and/or dissolution. After disaggregation or dissolution, any remaining insoluble residue was collected with a 100-mesh sieve and dried in an oven at 40 to 50 degrees Celsius for about 5 to 6 hours. Insoluble residues were examined under the microscope at 30x to 40x magnification to collect conodonts.

The collected conodonts were identified, counted and photographed by Darwin Boardman. Outcrop conodont biostratigraphic data were correlated to the composite measured section from the Type Chappel locality. Core and outcrop based stratigraphic data were correlated to the core description.

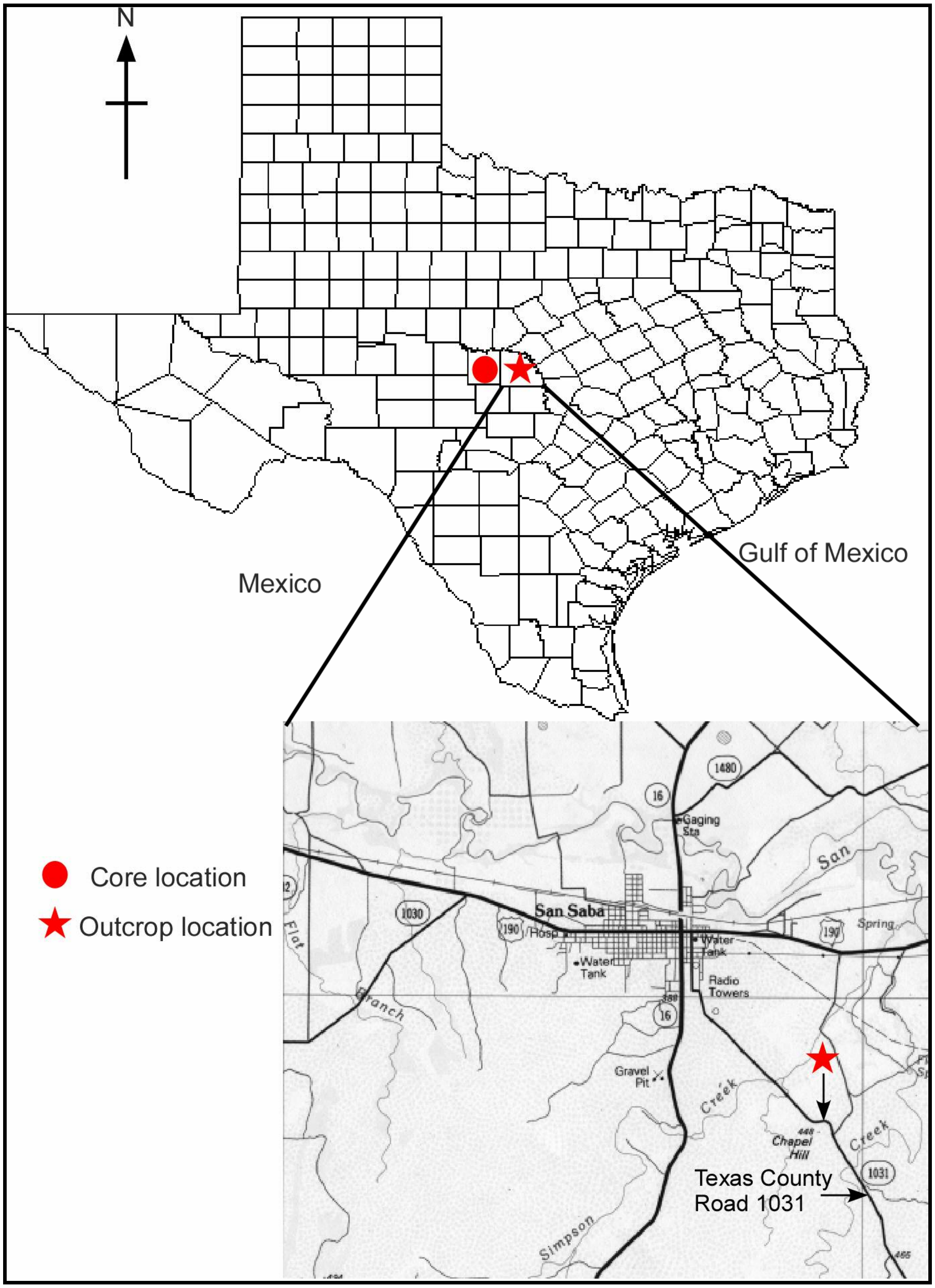


Figure 3. Map showing the locations of core, Johansen MC-1, (McCulloch County) and outcrop, Type Chappel Locality (San Saba County) in the Llano Uplift area, Texas. Type Chappel Locality is ~ 2.5 miles southeast of San Saba on Texas County Road, 1031.

CHAPTER III

GEOLOGIC SETTING

From the Cambrian to the Mississippian, the area that is now central Texas was part of a stable cratonic shelf, with deposition dominated by carbonates (Turner, 1957; Burgess, 1976). Ellenburger Group carbonate rocks represent a broad epeiric carbonate platform that covered virtually all of Texas during the Early Ordovician. A pronounced drop in sea level at the end of Ellenburger deposition resulted in prolonged platform exposure and extensive karst features in the upper part of the carbonate sequence (Sloss, 1976; Kerans, 1988). Moreover, a later major erosional event removed Silurian and Devonian rocks over a large area of Texas (Henry, 1982). Late Devonian-Early Mississippian strata (Ives Breccia, Houy Formation) are thin across the Central Texas and of questionable origin (Boardman, 2006).

During the Mississippian Osagean, the Chappel shelf formed. To the north, pinnacle reefs and mounds of the Chappel Limestone were deposited on the Ellenburger unconformity (Pollastro et al., 2006). In San Saba County the Chappel is a thin (~2 ft) carbonate that rests on the Ives Breccia (Kinderhookian? or Ellenburger) (Kier, 1972). To the northwest of the Fort Worth Basin, the lower Barnett Shale thins over the shelf and drapes over pinnacle reefs and mounds to form the seal for Chappel Limestone reservoirs (Pollastro, 2005).

Global plate reconstructions by Blakey (2005) suggest that during the middle to late Mississippian, the area occupied a narrow inland seaway between the rapidly approaching continents of Laurussia and Gondwana (Figure 4). This seaway was bounded on the west by a broad, shallow-water, carbonate shelf and on the east by an island arc chain (Blakey, 2005). On the basis of their studies of the Mississippian in Nevada, Gutschick and Sandberg (1983) constructed a paleogeographic map of the western margin of the Laurussian paleocontinent during the Mississippian that depicts the distribution of shelf and basin areas and presumed water depths (Figure 5). Arbenz (1989) concluded that the Forth Worth Basin formed as a foreland basin on the leading (southern) edge of the Laurussian paleocontinent. The Mississippian Interior seaway extended along most of the southern and southeastern margins of the Laurussian paleocontinent, across the entire area of what is now the southern United States (Figures 4 & 5). Oceanic circulation within this seaway was probably restricted and may have accounted for the disoxic to anoxic conditions indicated by the Barnett strata and equivalent rocks in Oklahoma & Arkansas (Loucks et al., 2007) (Boardman, 2007).In general, Mississippian rocks in the Fort Worth Basin and Llano Uplift area consist of alternating shallow marine limestones and black, organic-rich shales; however, the stratigraphy of the Mississippian section is not well defined because of lack of sufficient diagnostic fossils (Loucks et al., 2007)

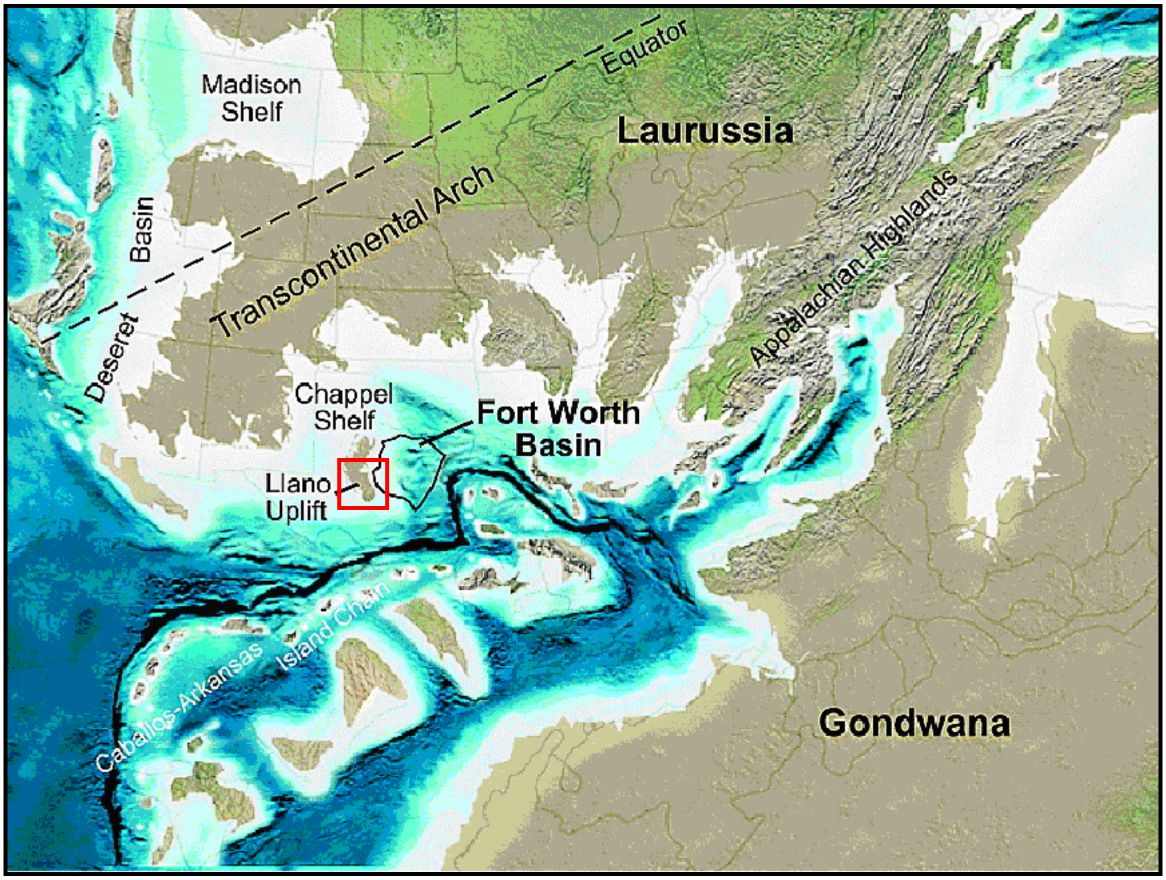


Figure 4. Regional paleogeography of the southern Mid-continent region during the late Mississippian (325 Ma) showing the approximate position of the Fort Worth Basin and Llano Uplift. Plate reconstruction by Blakey, R., (2005). Location of the study area is indicated by a red box mark.

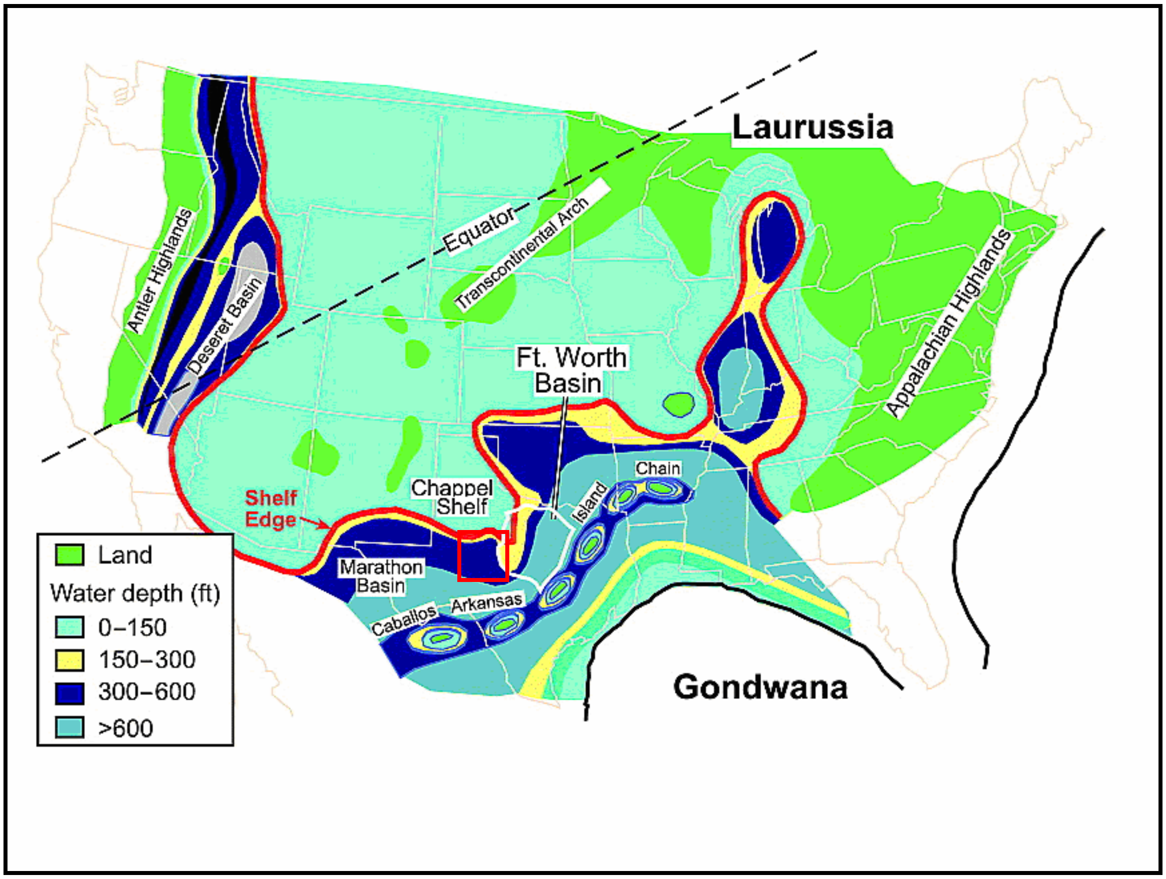


Figure 5. Middle Mississippian paleogeographic map of the United States based on studies by Gutschick and Sandberg (1983). This reconstruction suggests that the Forth Worth Basin was relatively deep; Chappel shelf was a shallow carbonate depocenter. Modified by Loucks et al., (2007) from Gutschick and Sandberg (1983). Location of study area is indicated by red box mark.

FORT WORTH BASIN

The Fort Worth Basin is a shallow, north-south – elongated trough encompassing roughly 15,000 mi^2 (38,100 km^2) in north-central Texas (Montgomery et al., 2005; Figure 6). It is one of several foreland basins associated with the late Paleozoic Ouachita Orogeny, a major event of thrust-fold deformation resulting from collisional tectonics during the formation of Pangea (Walper, 1982; Thompson, 1988). Other basins in this trend include the Black Warrior, Arkoma, Kerr, Val Verde, and Marfa basins (Flawn et al., 1961).

The Fort Worth Basin is a wedge-shaped, northward-deepening depression whose axis trends roughly parallel to the Ouachita structural front, which bounds the basin to the east (Montgomery et al., 2005) (Figure 6). A northern margin is formed by fault-bounded basement uplifts of the Red River and Muenster arches. These basement features have been interpreted to be part of the northwest-striking Amarillo–Wichita Uplift trend, created when basement faults associated with the Oklahoma aulacogen were reactivated during Ouachita compression (Walper, 1977; 1982). Westward, the Fort Worth Basin shallows against a series of gentle positive features, including the Bend Arch, Eastern Shelf, and Concho Platform. To the south, the basin is bounded by the Llano Uplift, a domal feature that exposes Precambrian and Paleozoic (Cambrian–Pennsylvanian) rocks (Montgomery et al., 2005; Figure 7).

LLANO UPLIFT

The Llano Uplift, (Figure 7) is a broad dome that is one of a family of uplifts and basins formed across southwestern North American during Late Paleozoic time (McGookey, 2005). The Llano Uplift had intermittent positive movements beginning in the Precambrian (Flawn et al., 1961). Sections of the Barnett Shale are exposed along the Llano Uplift in Lampasas and San Saba Counties (Grayson et al., 1991).

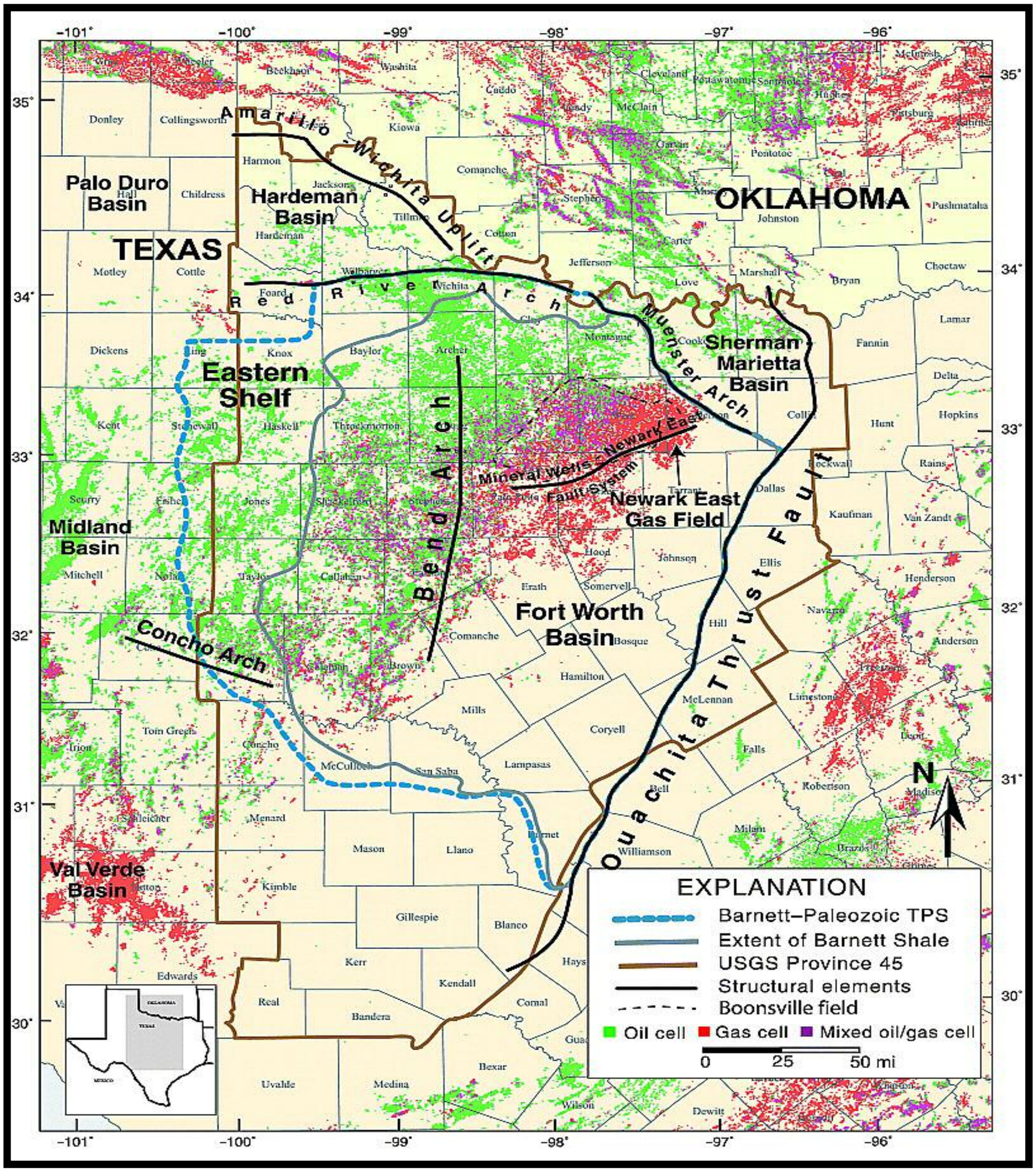


Figure 6. Map showing the area of U.S. Geological Survey (USGS) Bend arch−Fort Worth Basin province 45, major structural features, extent of Mississippian Barnett Shale and Barnett-Paleozoic Total Petroleum System. Cell size is equal to 0.25 mi^2 (0.64 km^2). (Pollastro et. al, 2007).

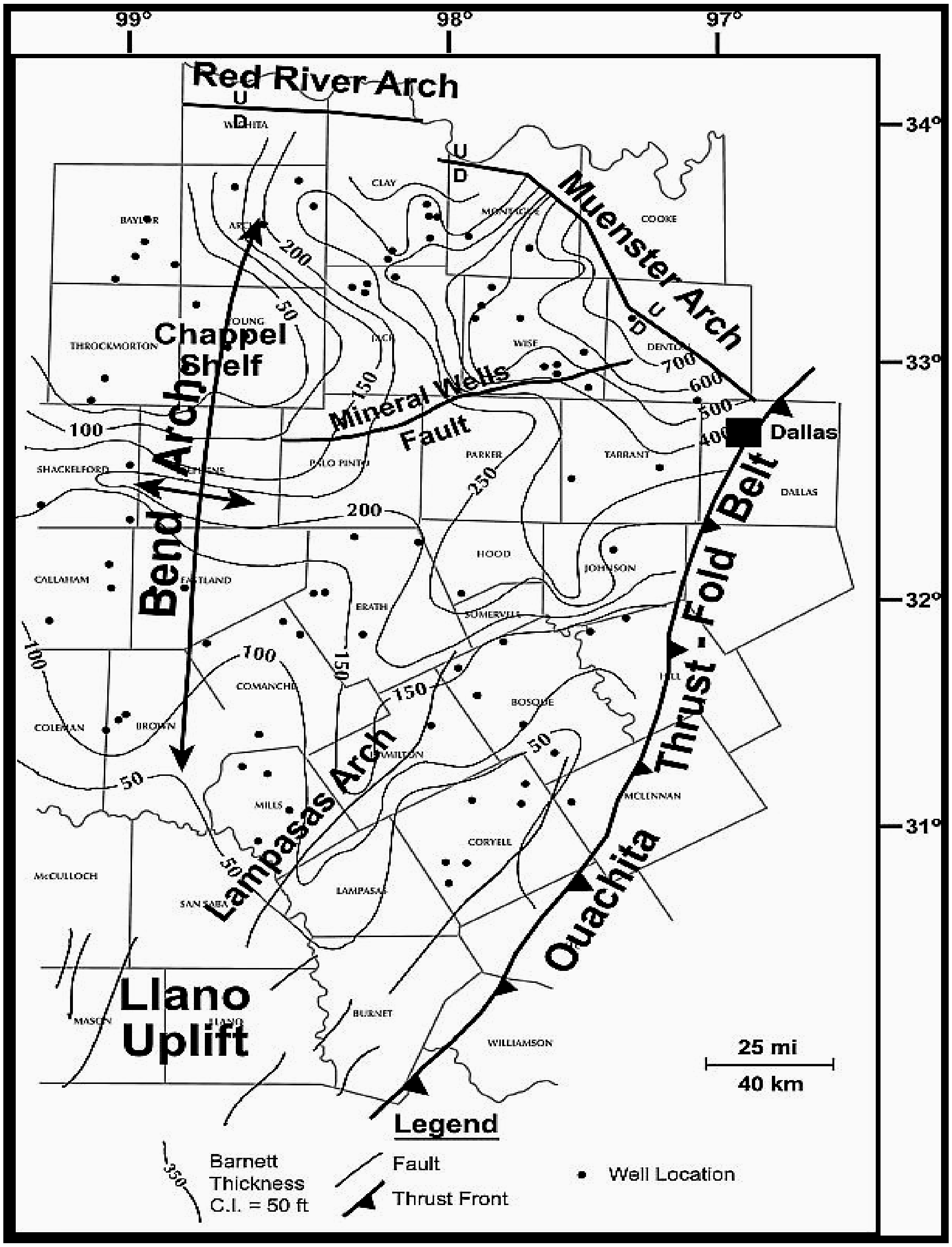


Figure 7. Generalized isopach map of Mississippian Barnett Shale, north-central Texas, Contour intervals: 50 ft (0 – 300 ft), 100 ft (>300 ft) (Montgomery et al., 2005).

NOMENCLATURE AND LITHOLOGY

According to Kier (1972), Girty (1912) recognized a shale interval at the base of the Bend Series between the Marble Falls Limestone (Pennsylvanian) and the Ellenburger Group (Ordovician). This shale was initially called the Lower Bend Shale by Udden, et al., (1916), but was subsequently named the Barnett Shale by Plummer and Moore (1922). In 1932, Sellards (Sellards, Adkins, and Plummer, 1932,) amended the name to “Barnett Formation” and gave the type locality as Barnett Springs.

In the northern Fort Worth Basin, the Barnett Shale is divided by the Forestburg Limestone. In the other areas, including the Llano Uplift, the Barnett Shale is a single unit that sometime contains the White’s Crossing Limestone at the base. Stratigraphy and lithology of the Barnett Shale change across the basin (Figure 1). In the Fort Worth Basin, the Barnett interval comprises a variety of lithofacies, which, with the exception of skeletal debris beds, are dominated by fine grained (clay to silt-size) sediment (Loucks, 2007). In outcrop the Barnett Shale is predominantly a light to dark brown, highly weathered, somewhat calichified shale. Fresh exposures are black to olive gray, very thinly laminated, and in some places, extremely petroliferous. Calcareous concretions within Barnett Shale are common and typically ellipsoidal to sub rounded. Some concretion beds are consistent across the outcrop. Concretions are dark brown, but progressively lighten to light brown towards the weathered surface. A freshly broken surface yields a strongly petroliferous odor. X-ray analyses shows that illite is the dominant clay mineral in the shale. Uranium is found throughout the Barnett, but not in economically useful quantities (Schwarz 1975).

DISTRIBUTION AND THICKNESS

The Barnett Shale is absent both north of the Muenster Arch in the Sherman-Marietta Basin and east of the Ouachita thrust belt (Figures 6 and 7). The present distribution of the formation (Figure 7) was determined by Pollastro (2003) using subsurface geophysical well logs, the IHS well-history database (IHS Energy, 2003), and the well data of Mapel et al. (1979). Barnett Shale is present in the Hardeman Basin to the north, where an oil-prone Barnett shale petroleum system, the Barnett-Hardeman Total Petroleum System (Figure 6), has been defined (Pollastro et al., 2004a, b). The Barnett Shale is also present in the Midland, Delaware, and Palo Duro basins to the west. Along the eastern shelf of the Midland Basin, the Barnett Shale is generally absent because of erosion and a facies change into limestone to the northwest along the Chappel shelf (Pollastro et al., 2007). Aerially small, isolated remnants of the shale facies have been identified on the karsted surface of the Ordovician Ellenburger Group (Mapel et al., 1979).

In the northern part of the Fort Worth Basin, the Barnett Shale averages approx. 250 ft (76 m) thick. It is thickest, (1000 ft[305 m]), in the deepest part of the basin adjacent to the Muenster Arch (Figure 7), where it is interbedded with limestone units that have a cumulative thickness of as much as 400 ft (122 m) (Mapel et al., 1979; Henry, 1982; Bowker, 2003; Pollastro, 2003; Texas Railroad Commission, 2003). The Barnett thins rapidly to the west to only a few tens of feet over the Mississippian Chappel shelf and along the Llano uplift (Pollastro, et al., 2007). In summary, the Barnett Shale is absent in areas (1) where eroded along the Red River Arch and Muenster Arch to the north and northeast; (2) along the Llano Uplift to the south; and (3) to the west, where there is an erosional limit and a facies change to limestone.

The Barnett exhibits a high gamma-ray log response at the base (basal hot shale in Figure 2) that can be traced throughout most of the basin. Thick (as much as 1000 ft [305 m]) sections of the Barnett Shale in the deepest part of the Fort Worth Basin adjacent to the Muenster Arch contain interbedded thick limestone units that are informally referred to as ‘‘limewash’’ in some places (Texas Railroad Commission, 2003). These limestones thin rapidly to the south and west away from the Muenster Arch. Bowker (2003) suggested that they were deposited as debris flows from a source to the north, probably the Muenster Arch.

CHAPTER IV

RESULTS

LITHOLOGIC DESCRIPTIONS

Type Chappel locality, San Saba, Texas

The apparently complete stratigraphic section of the Barnett Shale exposed in the road cut and adjoining shale quarry 2.5 miles southeast of San Saba, Texas was measured, described and sampled for conodont biostratigraphy. The stratigraphically lowest unit exposed in the road cut section is the Ordovician Ellenburger Limestone (Figure 8). The Ellenburger Limestone is unconformably overlain by the enigmatic Ives Breccia (Boardman & Puckette, 2006). The Ives Breccia consists of chert breccia as well as green shale and phosphatic limestone that contains conodonts that according to Hass (1953) are Late Devonian as well as Early Mississippian age (Kinderhookian). The Ives is overlain by the Chappel Limestone, which is Osagean in its entirety (Boardman & Puckette, 2006).

At the type Chappel locality, the measured total thickness of 41ft includes part of the Ellenburger Formation, the Ives Breccia, the Chappel Limestone, the Barnett Shale and lower Marble Falls (Figures 9, 10 and 11). The Barnett Shale at this location is 39.4 ft (12m) thick. Lithologically, the Barnett Shale is gray to black locally phosphatic shales (Figures 12 and 13) and thin interbedded carbonates. Most carbonates are lenticular and concretionary but traceable. They contain phosphatic mollusks (bivalves, gastropods, ammonoids, bactritoids). The Barnett Shale is locally rich in glauconite which gives a very high gamma ray value (Figure 11). The phosphatic rich zone in the quarry section at Type Chappel consists of laminar to sub-rounded phosphatic nodules (Figure 13). An exposure surface separates Chappel and Barnett at Type Chappel locality (Appendix A).

To the west of the San Saba outcrop a stratigraphically lower member is recognized that is below the black shale facies of the Barnett Shale. This lower member is carbonate and is known as the White's Crossing Member of the Barnett from its type locality at White's Crossing over the Llano River. No age data is available on this member even though Hass (1953) considered it to be older than the Barnett exposed at the Type Chappel locality (Boardman & Puckette, 2006).

The top contact is not exposed at the road cut, but is seen in a quarry across the road to the north. The contact between the Barnett Shale and Marble Falls Limestone is exposed on the quarry face and was dug out in a trench (Figure 14). The top of the Barnett Shale is calichified beneath the Marble Falls Limestone. The zone is rich in glauconite (1.3 ft) and phosphatized pellets and exhibits high gamma ray response (700 API) (Figure 11). This glauconitic zone has been interpreted to be the Chester/ Morrowan contact (Boardman & Puckette, 2006) (Figure 14).

At this locality, the Barnett Formation exhibits cyclic nature of deposition. Eight depositional cycles were interpreted at this locality (Figures 15 and 16). These cycles consists of fissile shale that grades upward into silty black shale and finally culminates with continuous carbonate beds or beds of carbonate concretions (Figures 17, 18 and 19). These cycles appear to represent shallowing upward parasequences. The overall Barnett Formation appears to shallow upward. The detailed description of the outcrop section is shown in Appendix A.

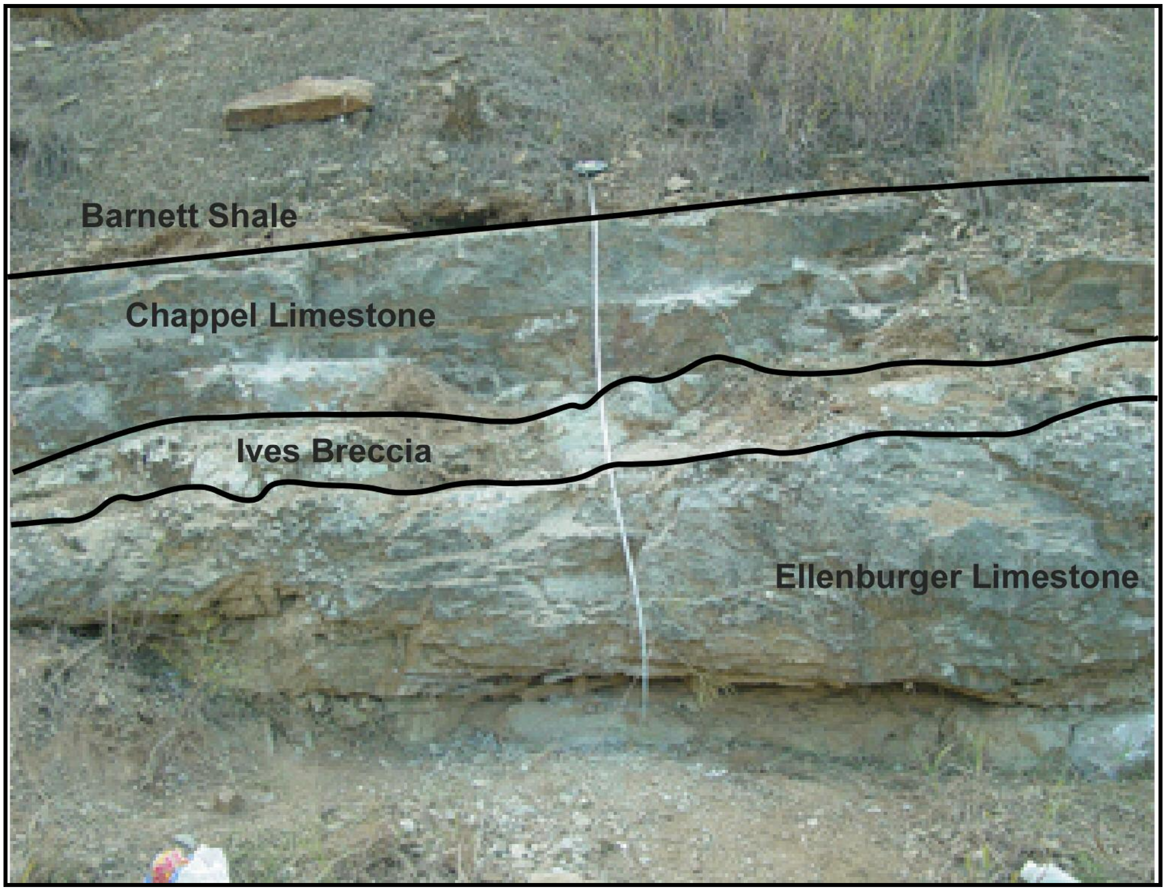


Figure 8. Ellenburger Limestone (Ordovician), Ives Breccia (Devonian-Mississippian), and Chappel Limestone (Mississippian) and lower Barnett Shale at Type Chappel outcrop, San Saba, Texas. Tape is approximately 5 ft in length (modified after Boardman & Puckette, 2006).

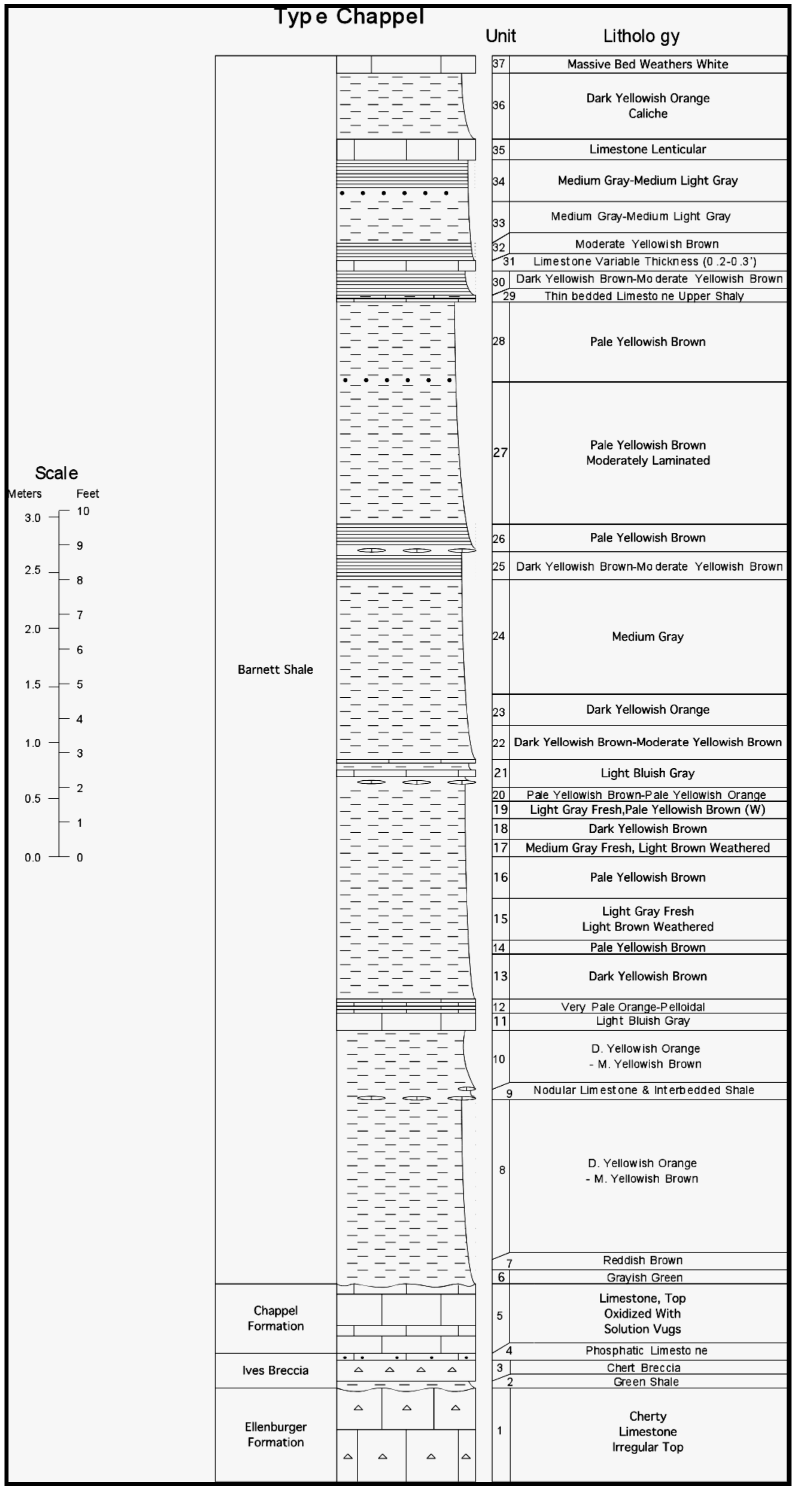


Figure 9. Litholog showing road cut lithology and cyclic nature of Barnett Shale deposition at Type Chappel locality, San Saba, Texas (Boardman & Puckette, 2006).

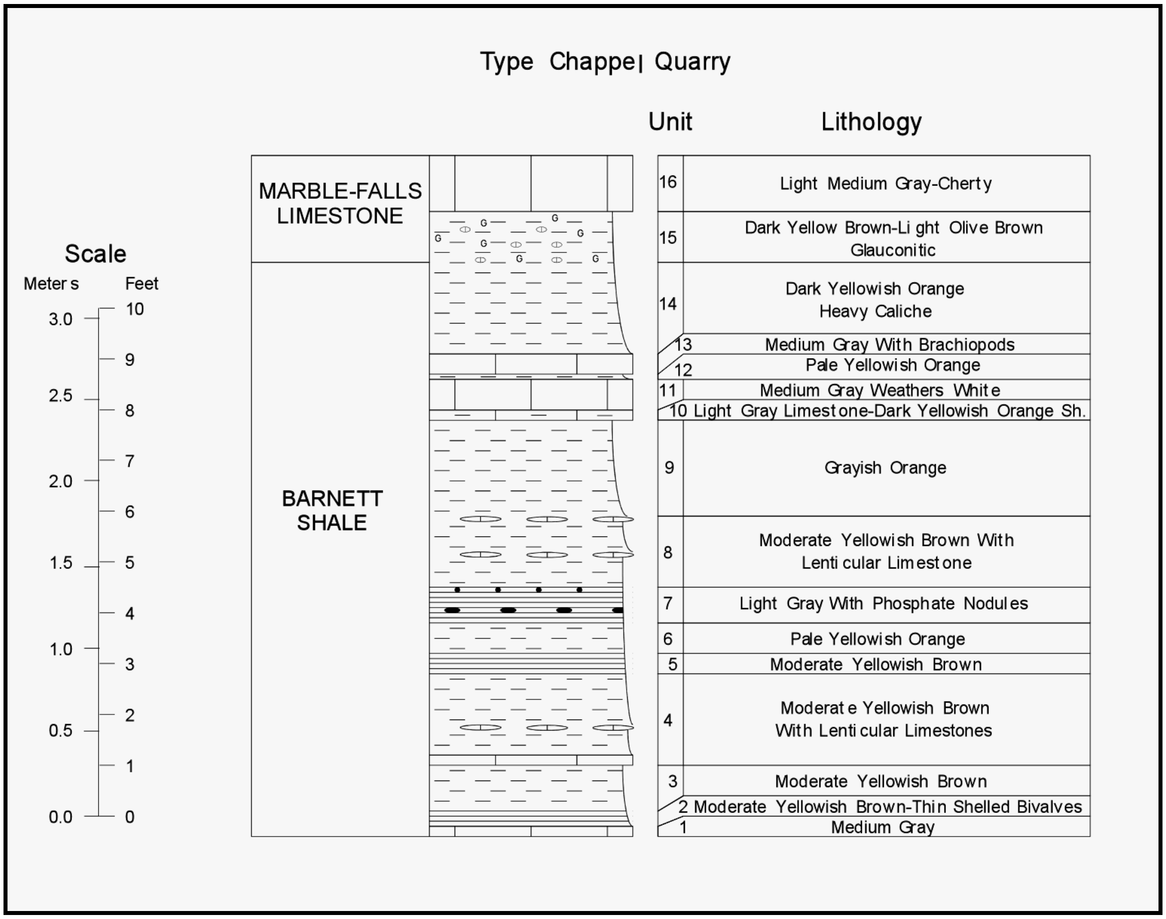


Figure 10. Litholog showing lithology of Barnett Shale, quarry section, at Type Chappel locality San Saba, Texas (Boardman & Puckette, 2006).

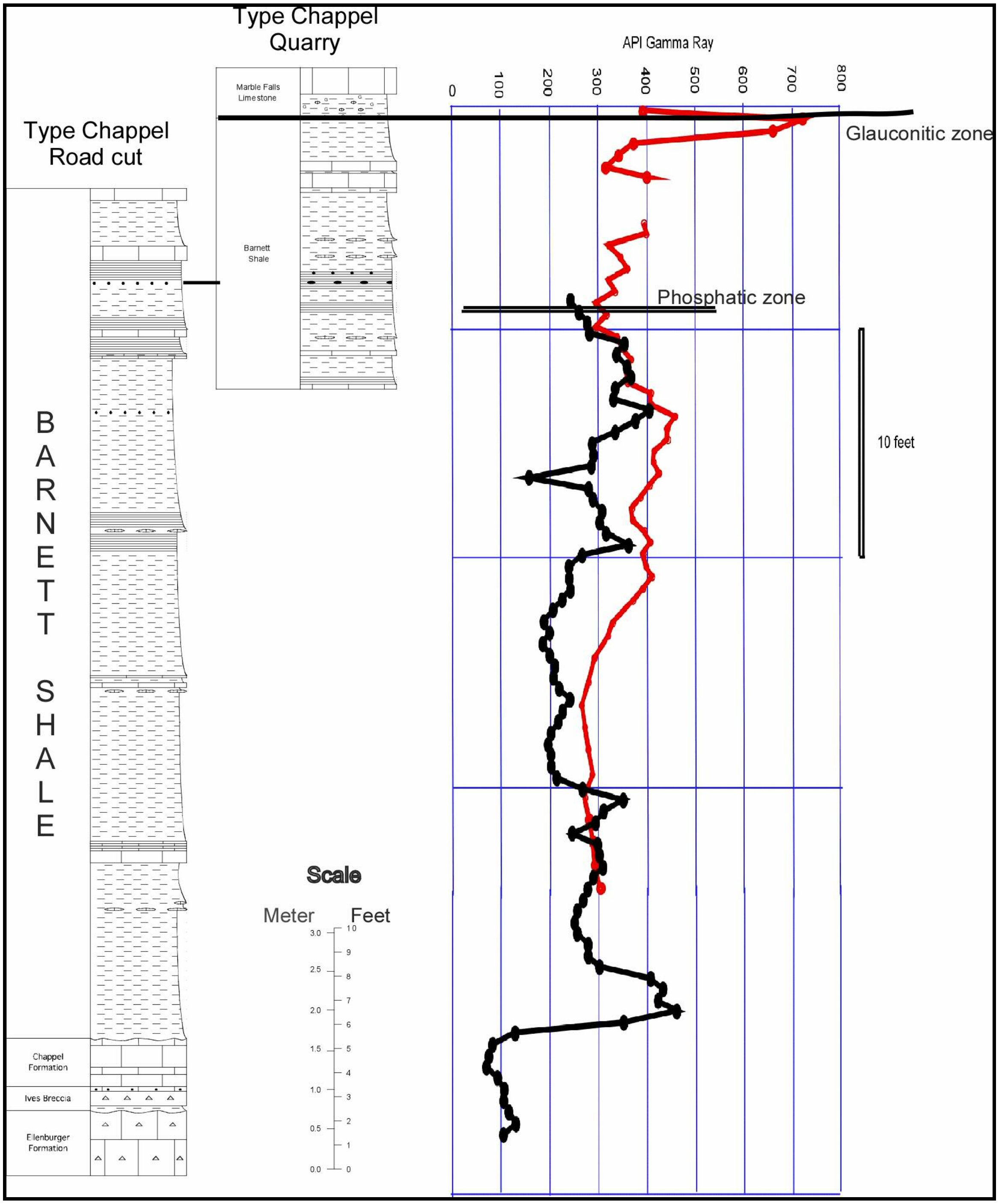


Figure 11. Correlation of gamma ray curve against composite section of Type Chappel at San Saba, Texas. Glauconitic zone at the top of the picture represents the boundary between Barnett Shale & Marble Falls Limestone at this locality (Modified after Boardman et al., 2007).

Figure 12. Upper Barnett Shale quarry section showing the location of the phosphatic zone and cyclic nature of the Barnett Shale deposition. White limestone at upper part of the picture is top of cycle 7 and appears to be correlatable to limestone along the road at the Type Chappel locality (modified after Boardman et al., 2007).

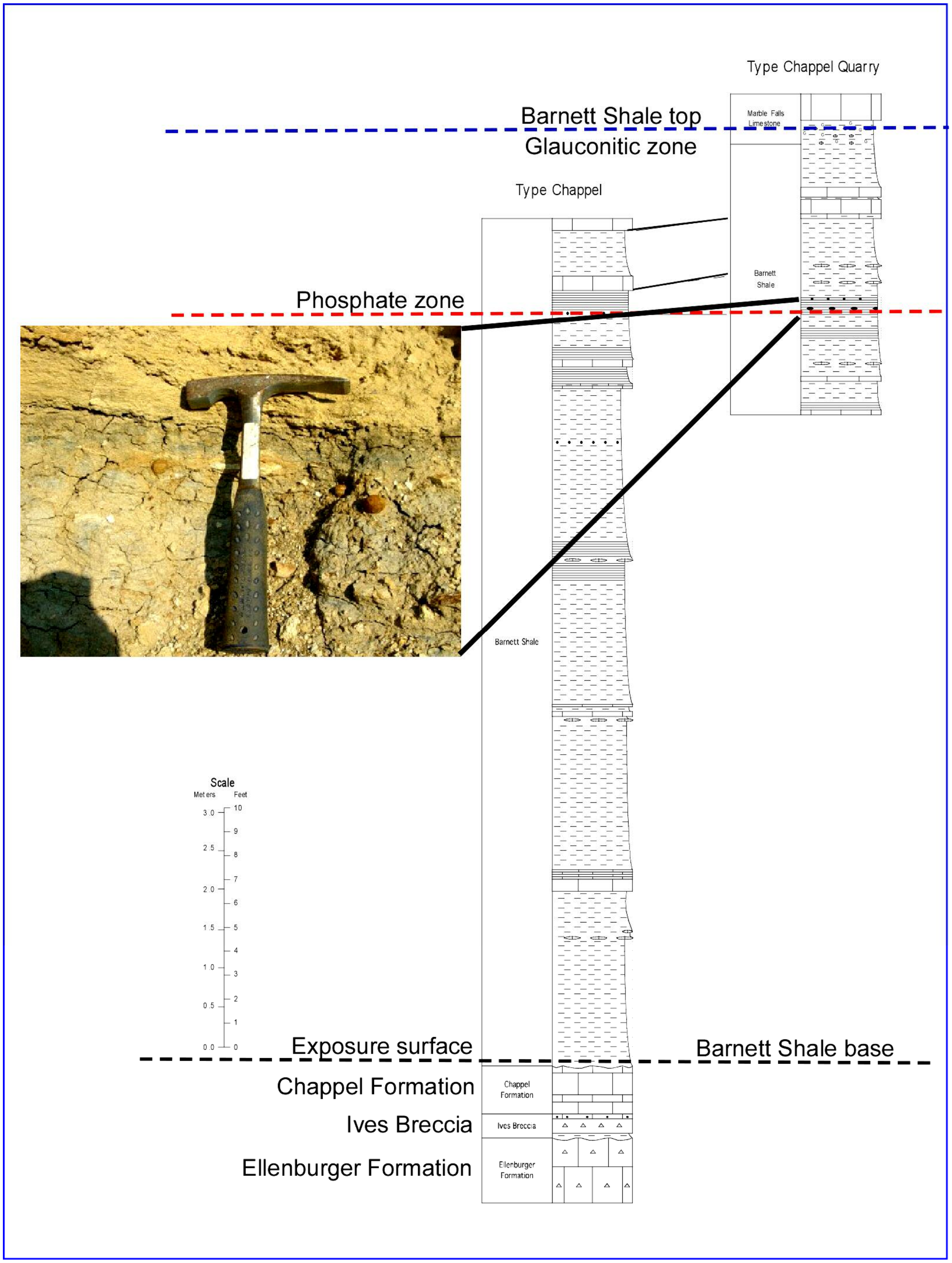


Figure 13. Photograph showing laminar and nodular phosphate within the Barnett Shale in the west wall of the quarry at Type Chappel locality, San Saba, Texas (modified after Boardman et al., 2007).

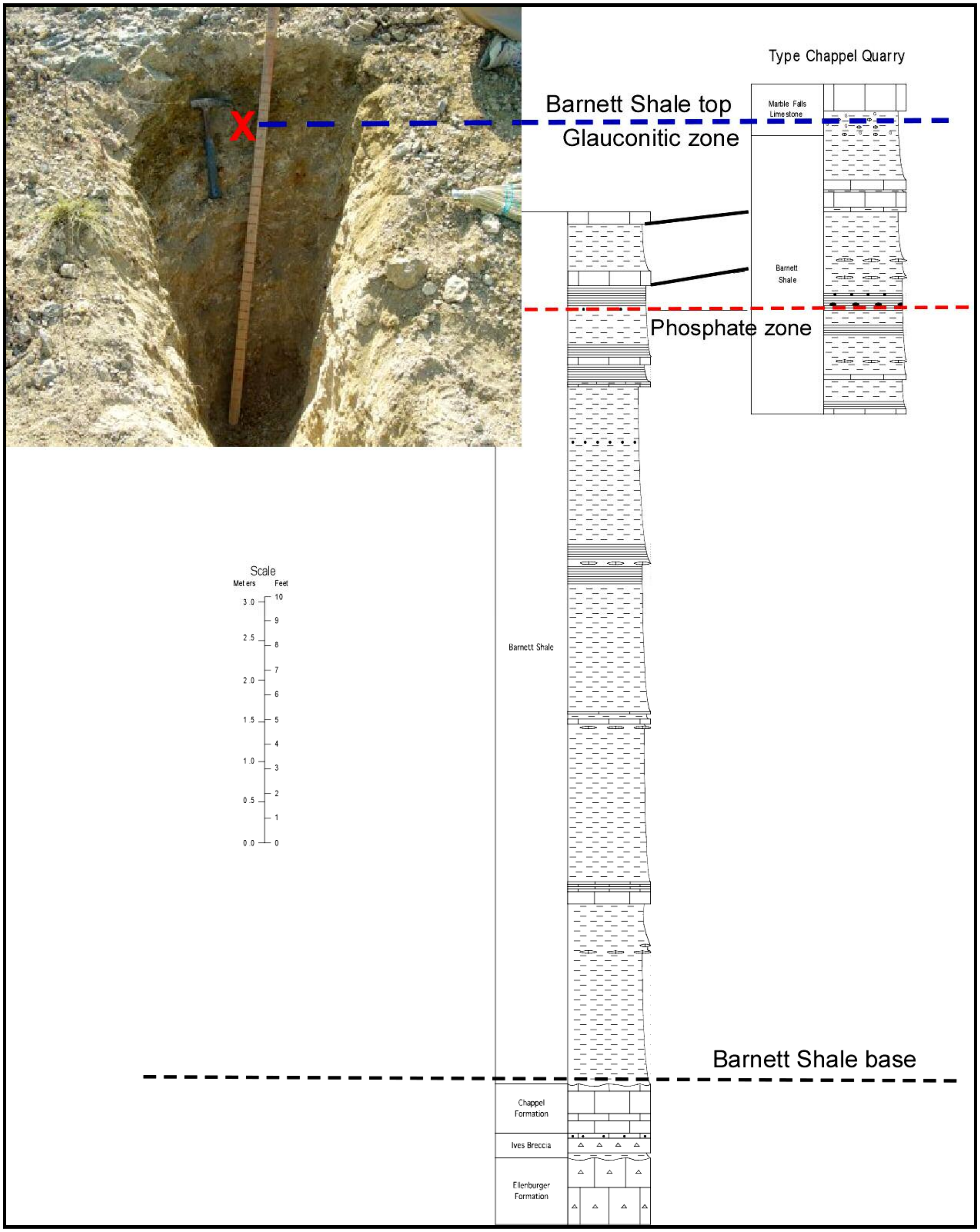


Figure 14. Photograph showing the contact between the shale and the overlying limestone at Type Chappel locality, San Saba, Texas. The top of the Barnett Shale is a glauconite-rich zone (red cross) in the trench (modified after Boardman et al., 2007).

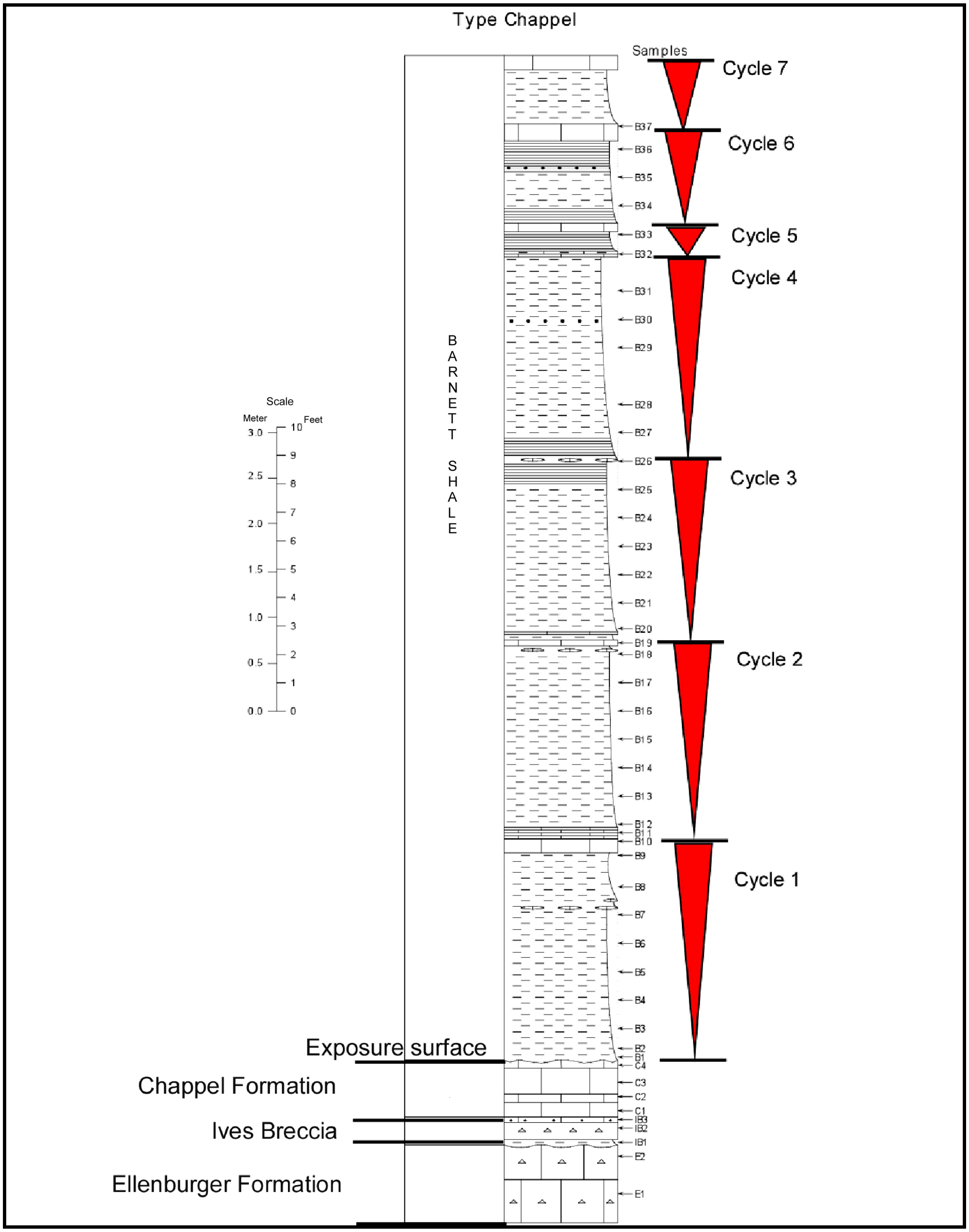


Figure 15. Schematic diagram of the road cut section of Barnett Shale at Type Chappel locality and the number of cycles of deposition within the Barnett.

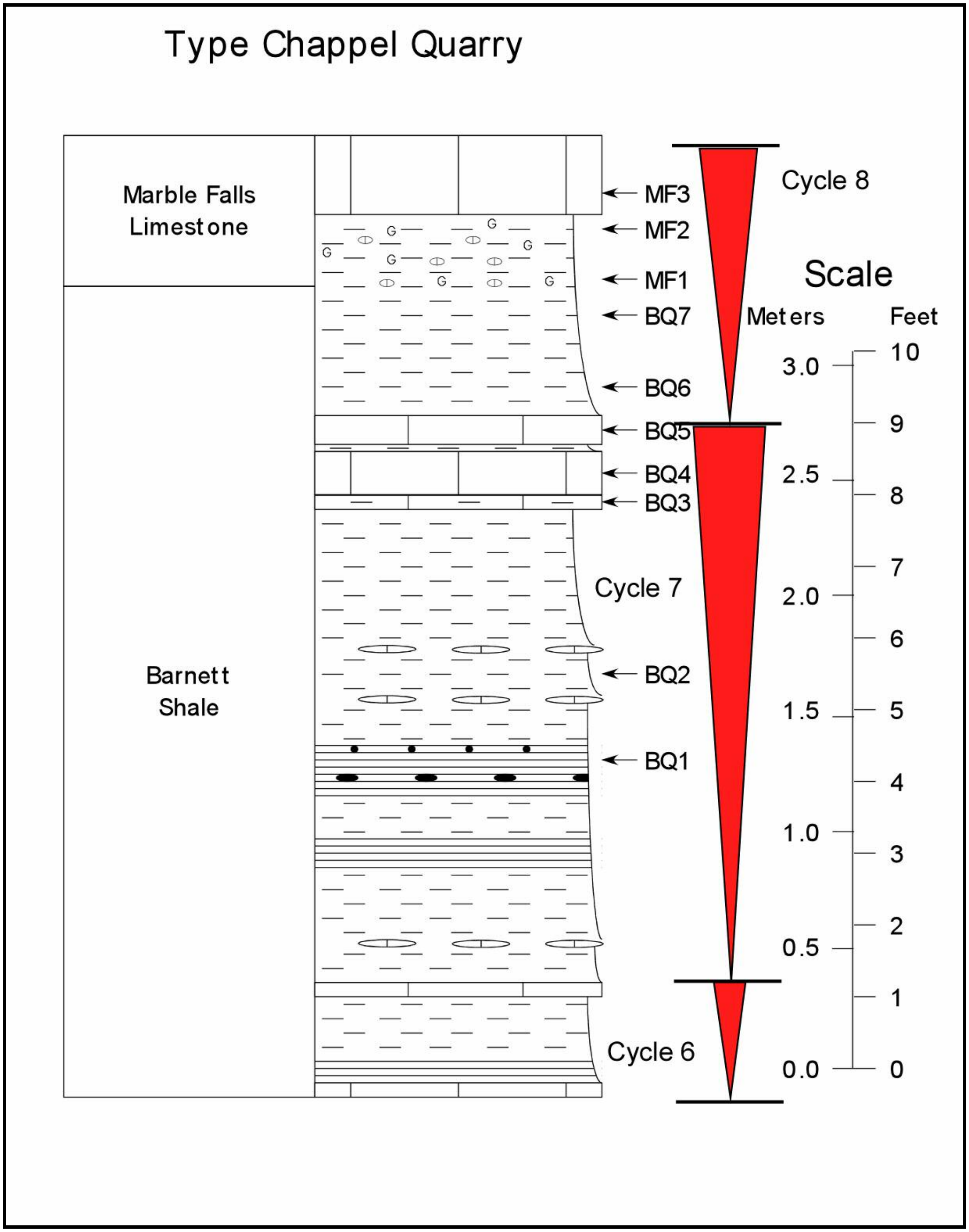


Figure 16. Schematic diagram of the Quarry section of Barnett Shale at Type Chappel locality and the last cycle of deposition within the Barnett Shale. BQ and MF stands for Barnett quarry and Marble Falls respectively and the numbers represent different units (modified after Boardman et al., 2007).

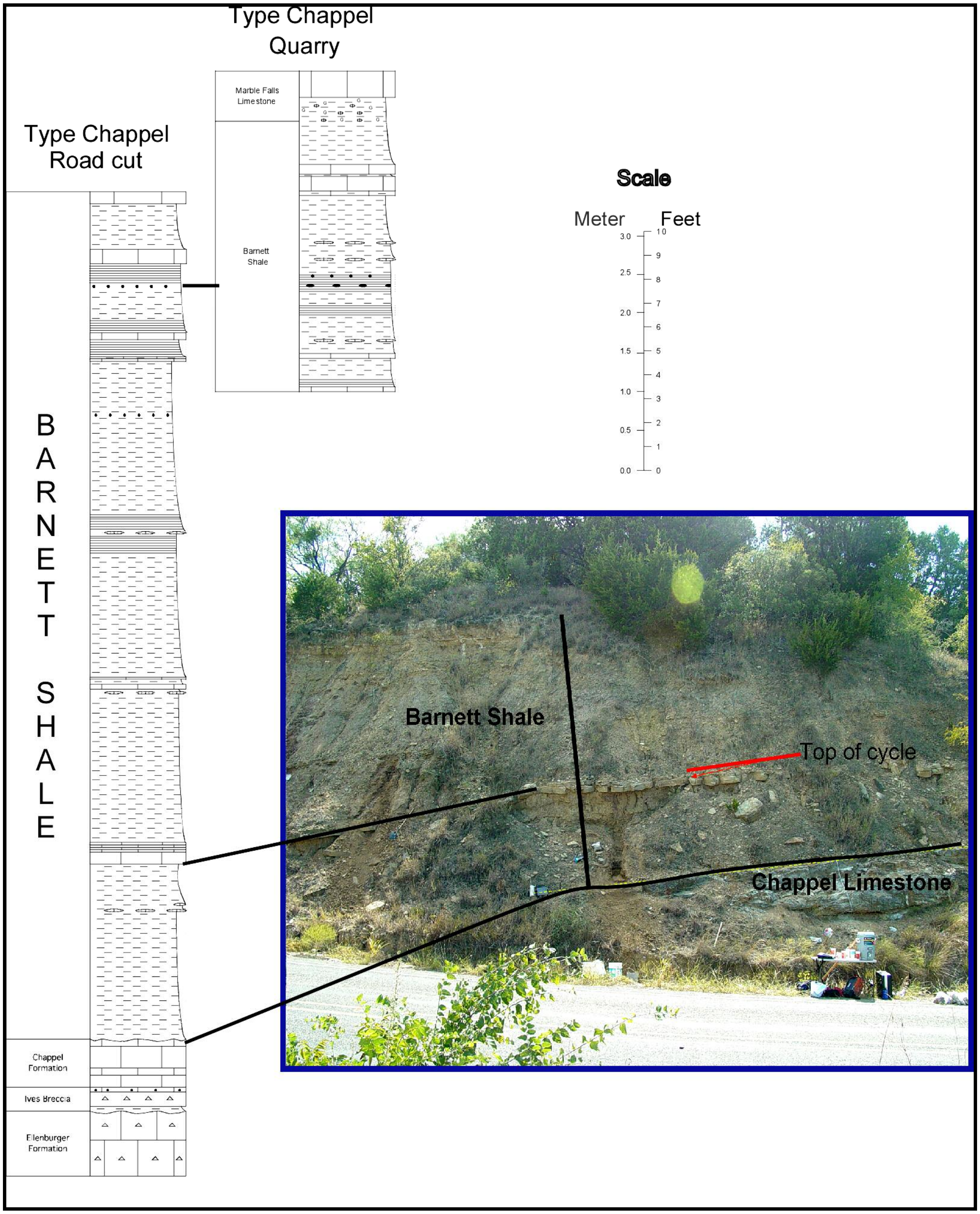


Figure 17. Barnett shale with underlying Chappel at Type Chappel outcrop, San Saba, Texas. Depositional cycle one within the Barnett Shale, culminates with a prominent limestone ledge shown in the photograph (modified after Boardman et al., 2007).

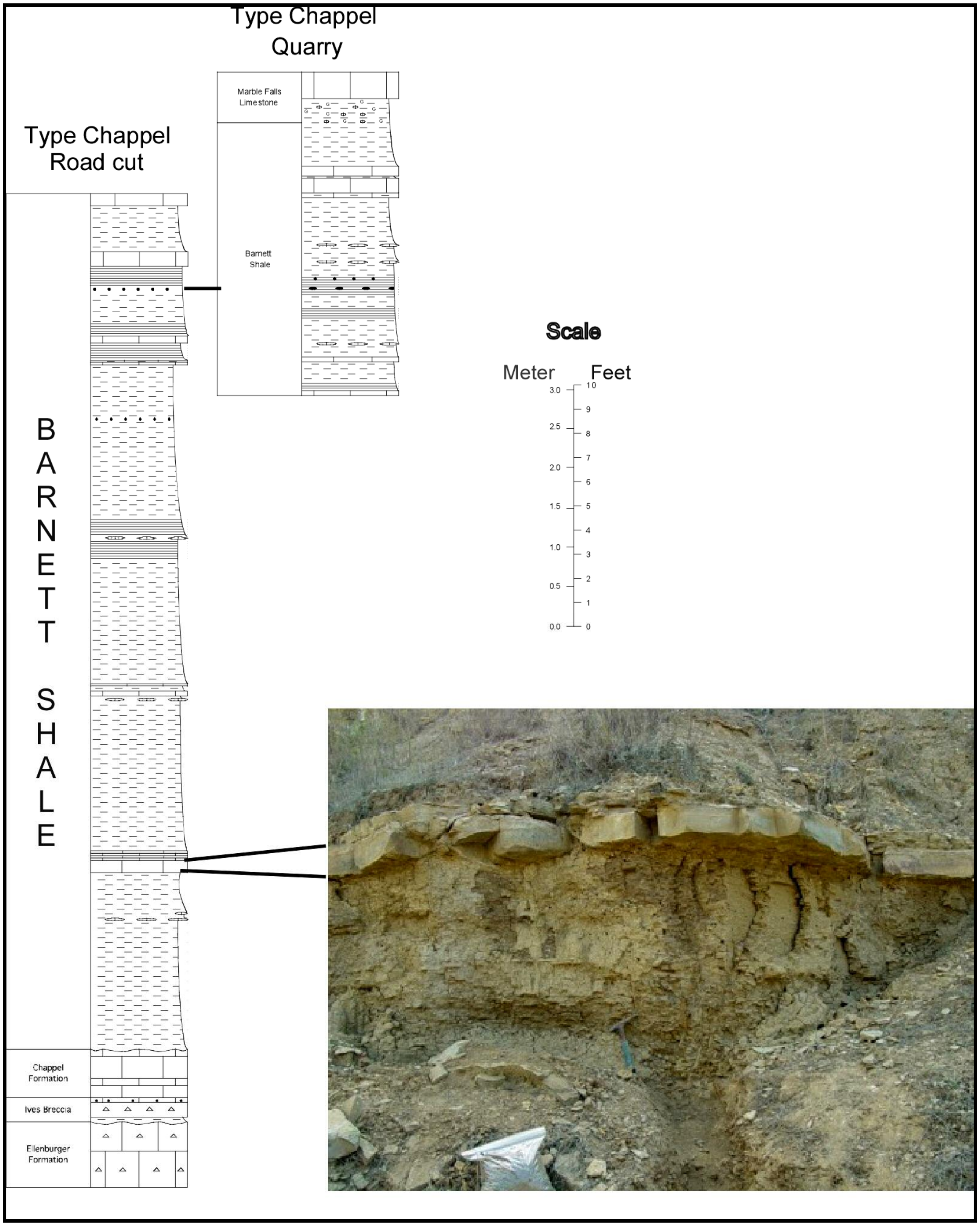


Figure 18. Photograph from the Type Chappel Locality showing the close up of the first limestone ledge which represents the culmination of the fist depositional cycle within the Barnett Shale.

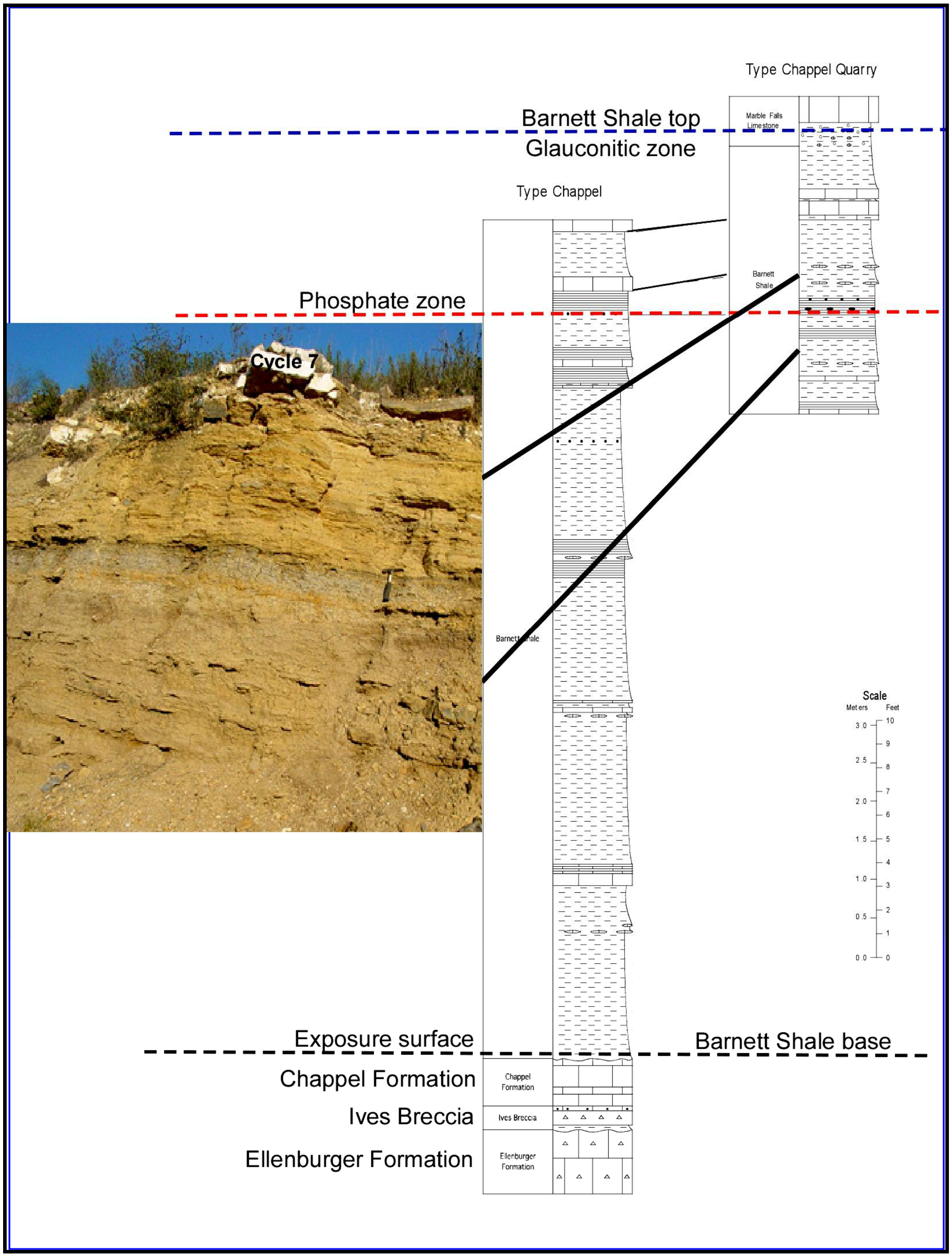


Figure 19. Photograph showing the location of the gray-colored phosphate-rich zone in the Barnett quarry and the cyclic nature of Barnett Shale deposition at Type Chappel locality, San Saba, Texas. White Limestone at the top of the picture is top of cycle 7 and appears to be correlatable to limestone along the road at the Type Chappel locality.

JH MC-1 Well Core, McCulloch Co., Texas

The examination of the shallow core from Johansen MC-1 Well, McCulloch, County, Texas, revealed that it contains Chappel Limestone, White's Crossing Limestone, Barnett Shale, Marble Falls Limestone, and Smithwick Shale. A lower section of the core, which was not provided for study, contains the Ellenburger Limestone. For this study, the core was described and sampled from 1134 to 1150 ft, which includes the stratigraphic interval from the Chappel Limestone to Marble Falls Limestone (Figure 20). The Chappel Limestone is four (4) feet thick, White's Crossing Limestone: forty two feet (42 feet), Barnett Shale: thirty feet (30 feet), and Marble Falls Limestone: ninety three feet (93 feet). A detail core description based on lithological changes and faunal content is shown in Appendix B. Lithologically the Chappel Limestone in this core ranges from fossiliferous poorly consolidated glauconitic crinoidal packstone to oolitic grainstone (Plate 16, Appendix B). In this core, the top of Chappel Limestone is red colored (hematite stained) indicating a nearby subaerial exposure surface. The White's Crossing Limestone unconformably overlies on the Chappel Limestone. This carbonate is primarily crinoidal grainstone containing crinoids (Plate 15, Appendix B). Two thin marl/mudstone sections are observed within the White's Crossing Limestone.

The contact between White's Crossing Limestone and Barnett Shale is gradational (Figure 22). The Barnett Shale is dark colored organic-rich, siliceous shale with pyrite, disarticulated brachiopods and crinoids (Plates 10, 11 and 12, Appendix B). Some of the units within Barnett Shale are rich in glauconite that is easily observed in thin sections (Plates 13 and 14, Appendix B). The upper part of the Barnett Shale consists of greenish gray shale that is highly broken, and has smooth and waxy feel. This zone is interpreted as an exposure surface (Figure 24). This exposure surface forms a sharp contact between the Barnett Shale and the overlying Marble Falls Limestone. The Marble Falls Limestone consists of mixed grainy carbonates (Plates 8 and 9, Appendix B).

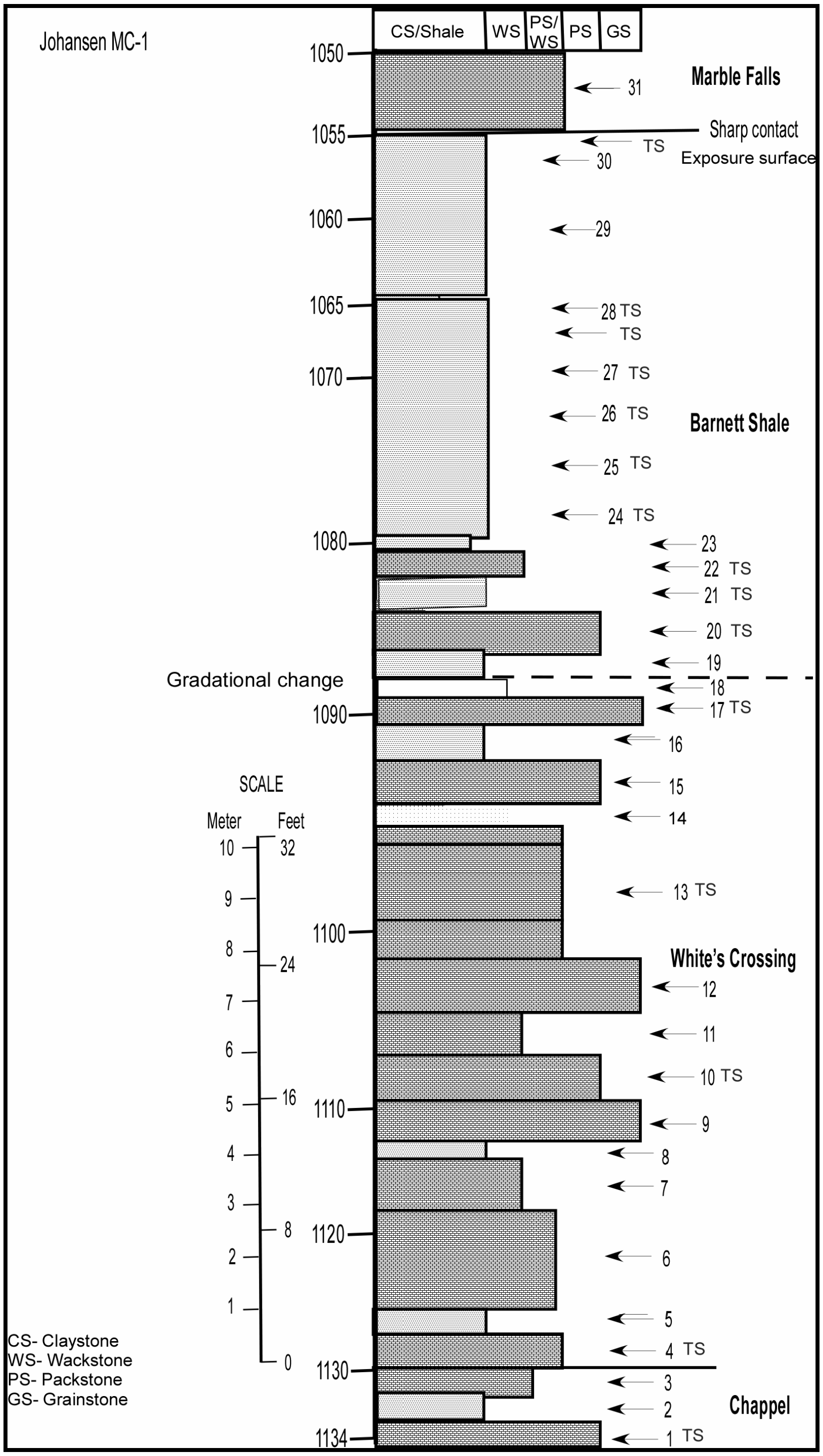


Figure 20. Litholog from the shallow core, JH MC-1, McCulloch County, Texas. Different units within the core are marked by an arrow and thin section locations are marked as TS.

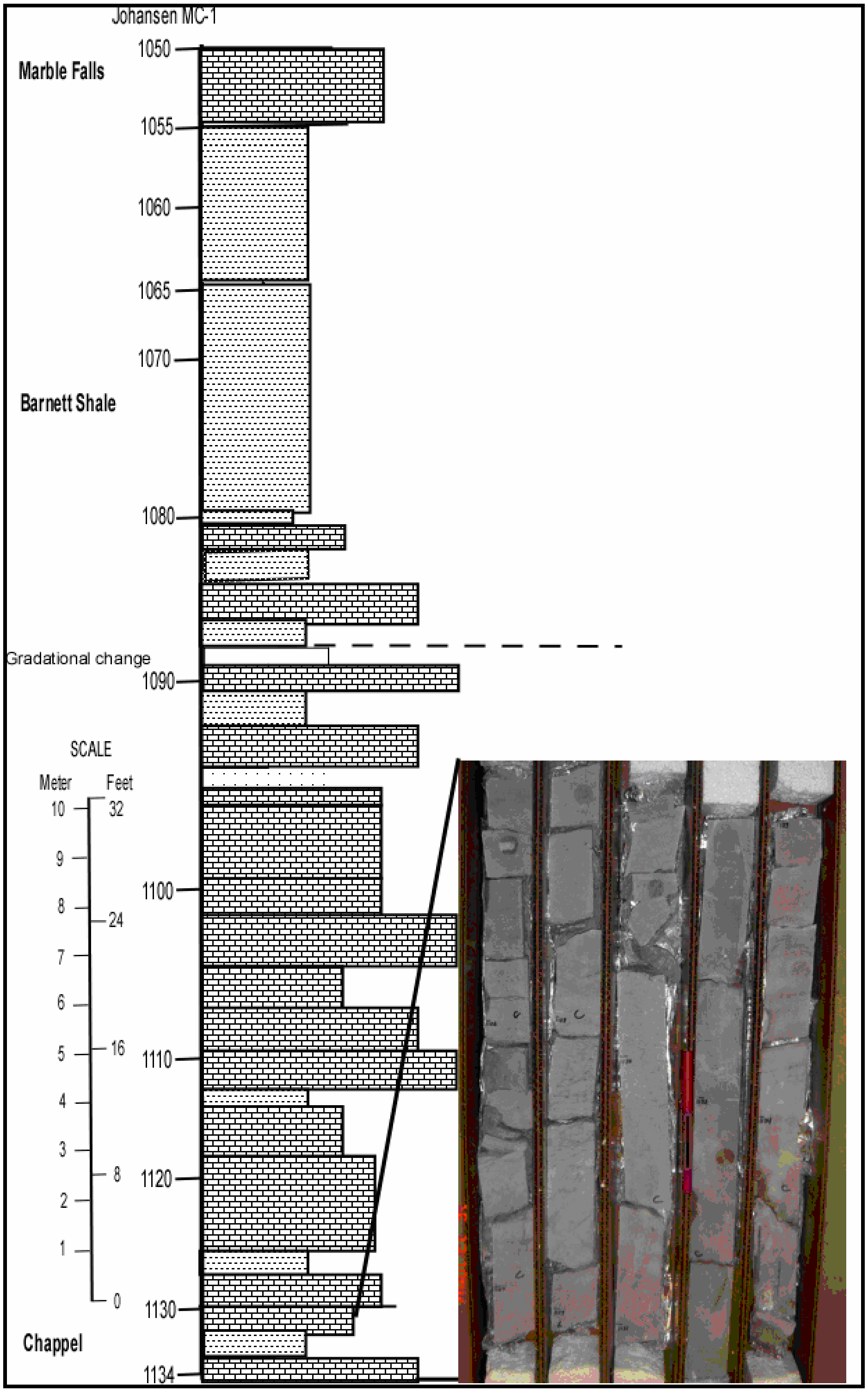


Figure 21. Core photograph of the lower Chappel Limestone from the shallow core, JH MC-1.

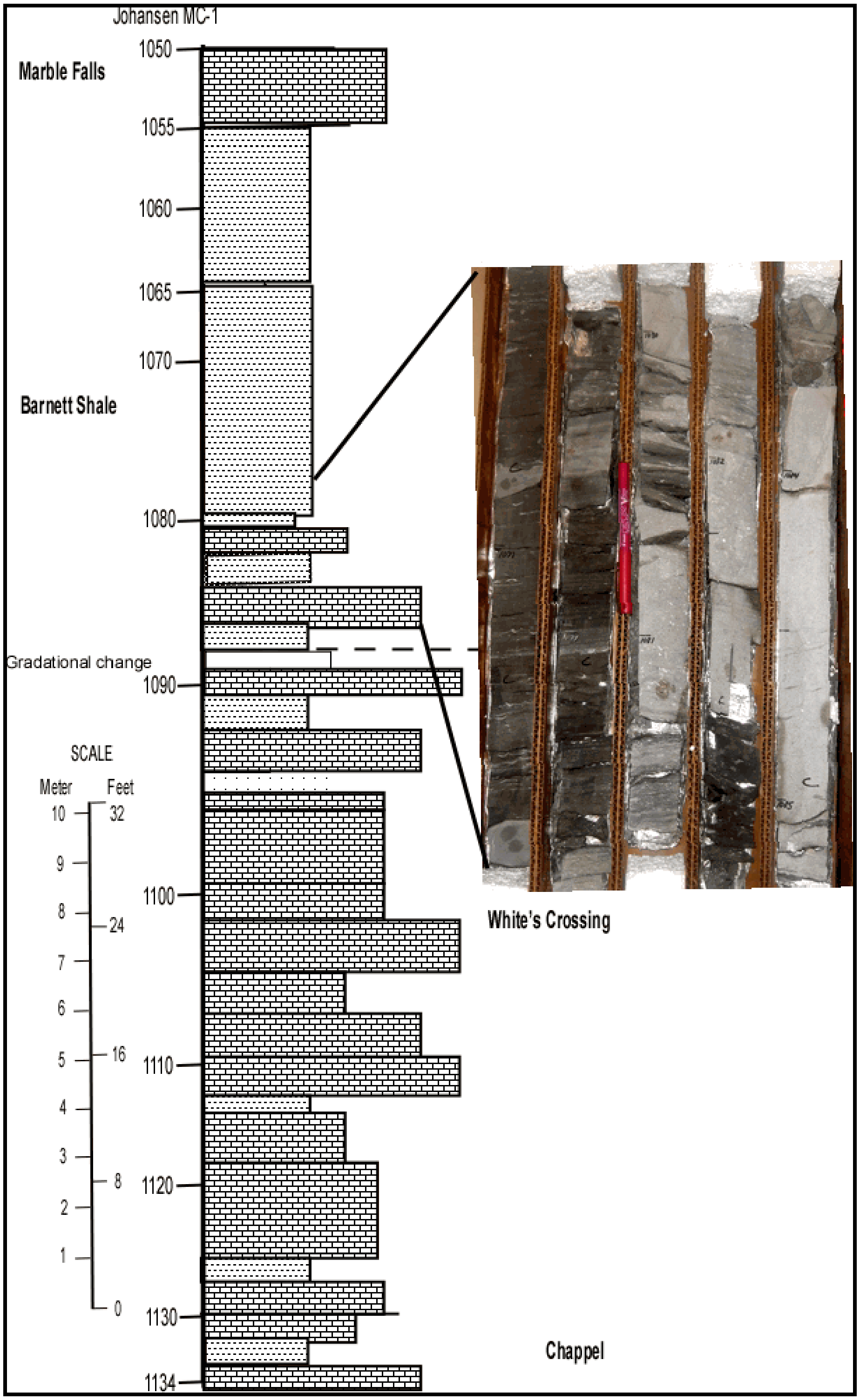


Figure 22. Core photograph of the transition from White's Crossing Limestone to dark organic rich Barnett Shale, from shallow core, JH MC-1.

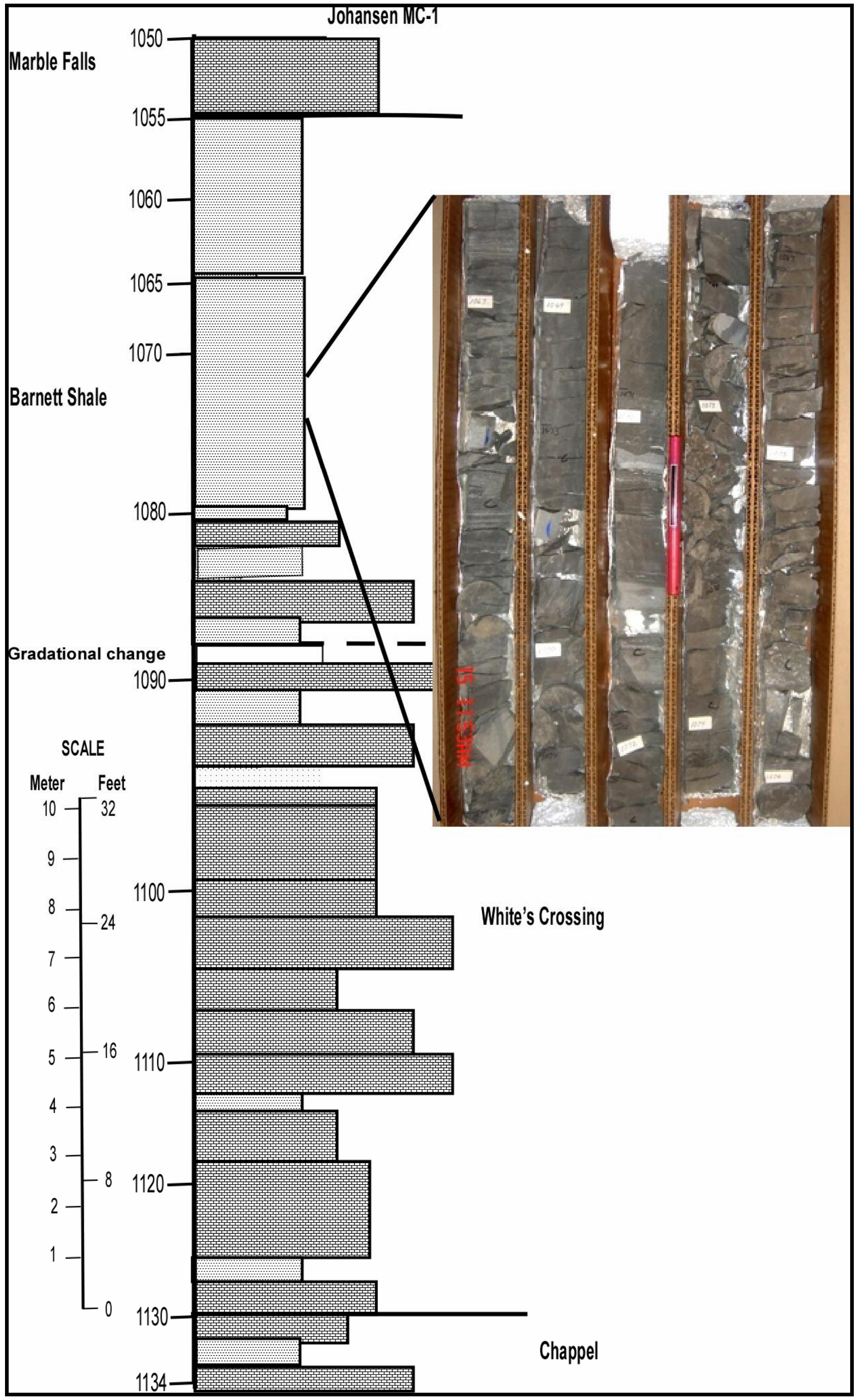


Figure 23. Highly brittle, silica rich zones within Barnett shale from shallow core, JH MC-1.

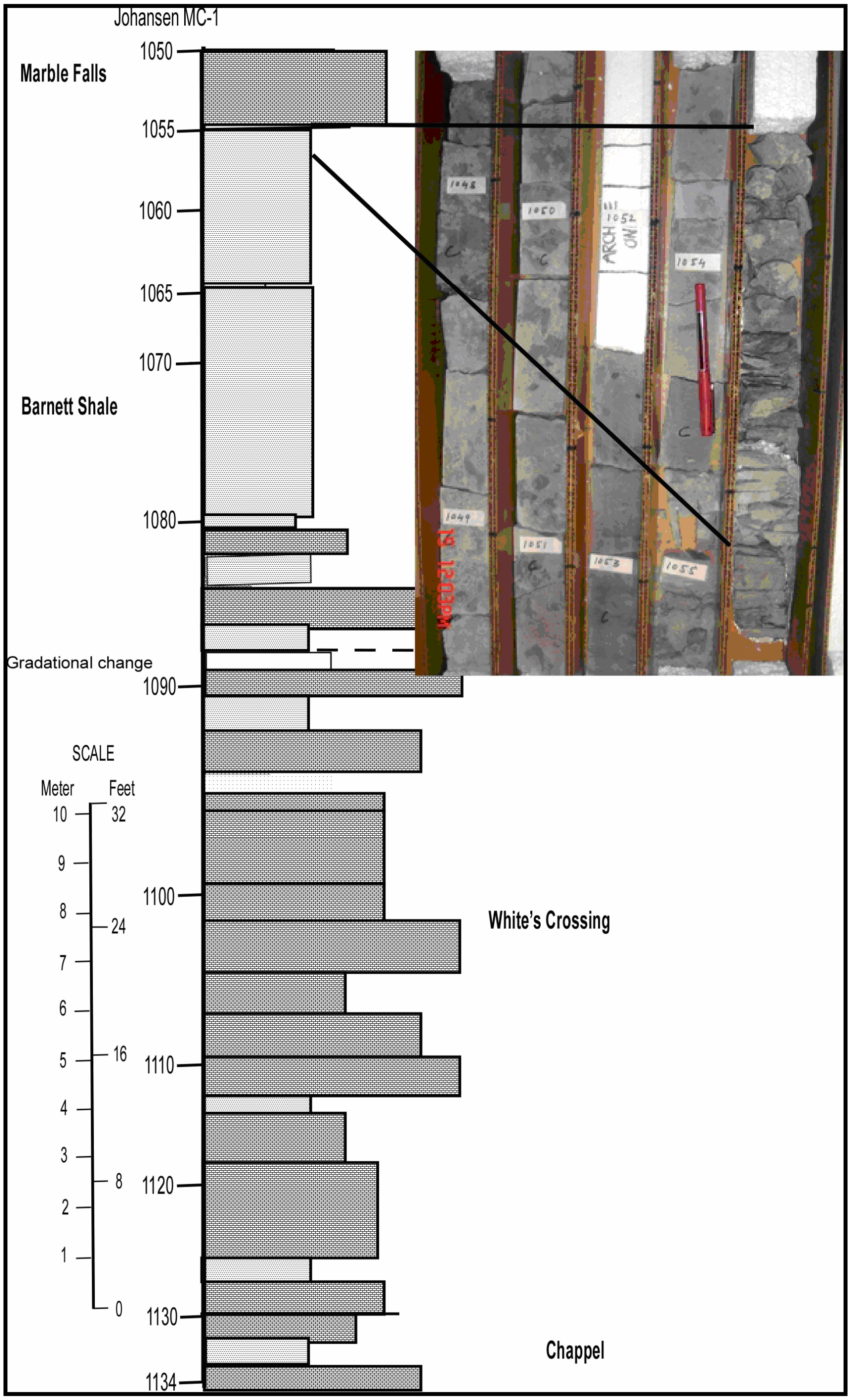


Figure 24. Core photograph showing the contact between the Upper Barnett Shale and Lower Marble Falls Limestone. The shale at the top consists of broken pieces of mudstone/claystone, which has a smooth and waxy that is characteristic of an exposure surface.

CONODONT BIOSTRATIGRAPHY

Type Chappel Locality, San Saba, Texas

Haas (1953) had identified two conodont zones within the Barnett Shale. However, according to Haas, the lower zone occurred near White's Crossing of the Llano River in carbonates. No specific distinction was given between the two faunal zones.

In this study, sampling and conodont recovery was throughout the interval. Abundances varied from less than 5 PA elements per 500 grams to over 100 PA elements per 500 grams. On the basis of recovery, 6 abundant intervals were identified and out of these, 3 faunal intervals are easily recognizable. However, detailed morphological analysis might be able to further subdivide these faunal zones (Boardman, 2006). These faunal zones contain locally abundant glauconite, and phosphatic pelloids.The faunal classification (Boardman, 2006) at Type Chappel outcrop is listed below.

<u>Lower Barnett Fauna (Mississippian-uppermost Meramecian or lowermost Chesterian) from cycles 1-3 (Figure 16), Plate 6</u>

1. Lower Faunal Interval- *Gnathodus texanus*, Nos. 1 & 2
2. Lower Faunal Interval- *Lochriea commutate*, Nos. 3 & 4
3. Lower Faunal Interval- *Gnathodus bilineatus*, Nos. 5, 6 & 7
4. Lower Faunal Interval- *Gnathodus girtyi*, No. 8

<u>Upper Barnett Fauna (Mississippian-upper Chesterian) from cycles 4-5 (Figure16), Plate 7</u>

1. Upper Faunal Interval- *Gnathodus bilineatus* (late Morphotypes), Nos. 1,2, & 3
2. Upper Faunal Interval- *Lochriea commutate*, No. 4

3. Upper Faunal Interval-*Lochriea monodosus*, No. 5

4. Upper Faunal Interval- *Lochriea nodosus*, No. 6

<u>Top Barnett Fauna (Lower Morrowan) from cycles 7- 8 (Figure 17), Plate 8</u>

1. Top Barnett Faunal Interval *Idiognathoides sinuatus*, No. 1

2. Top Barnett Faunal Interval *Neognathodus symmetricus*, No. 2

3. Top Barnett Faunal Interval *Declinognathus* sp., No. 3

Plate 1. Lower Barnett Shale (Mississippian-uppermost Meramecian or lowermost Chesterian)

1. Lower Faunal Interval- *Gnathodus texanus*, Nos. 1 & 2
2. Lower Faunal Interval- *Lochriea commutata*, Nos. 3 & 4
3. Lower Faunal Interval- *Gnathodus bilineatus*, Nos. 5,6 & 7
4. Lower Faunal Interval- *Gnathodus girtyi*, No. 8

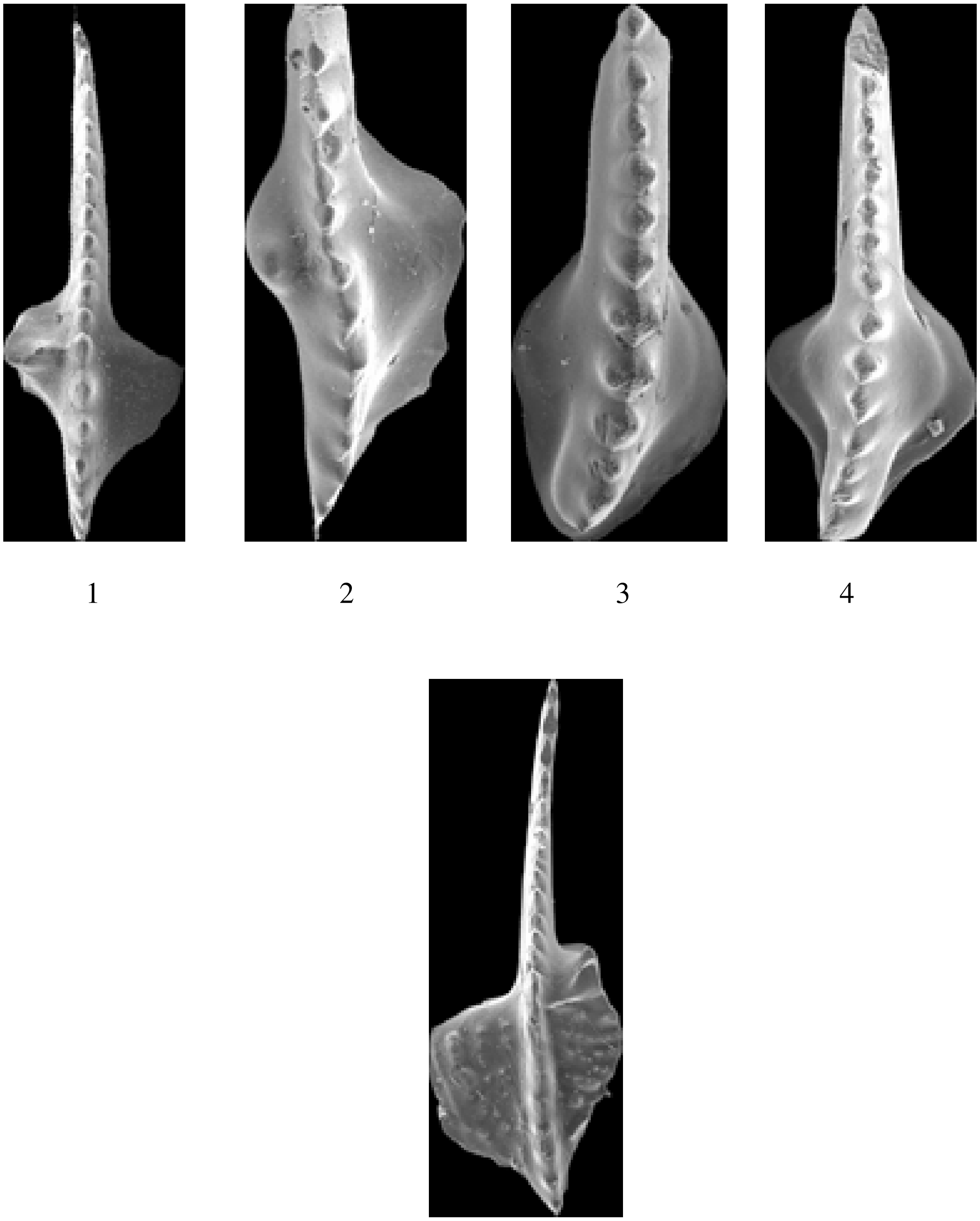
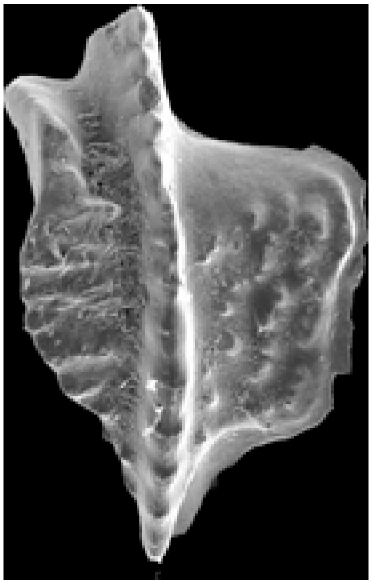


Plate 1. Lower Barnett Shale forms (Mississippian-uppermost Meramecian or lowermost Chesterian).



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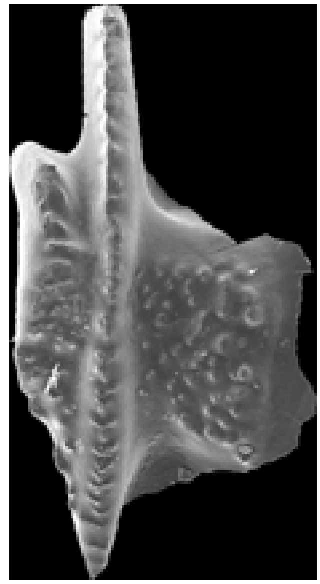

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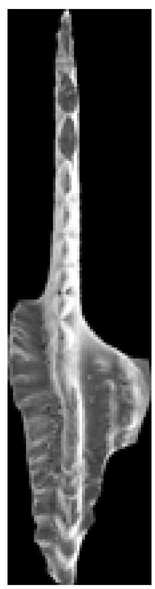

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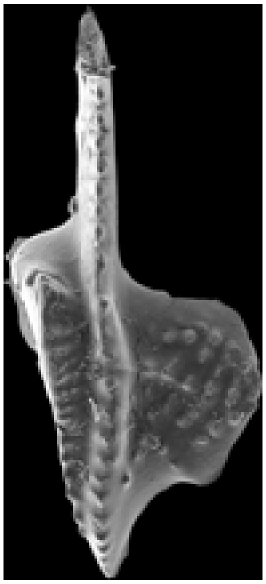
Plate 1. (Continued) Lower Barnett Shale forms (Mississippian-uppermost Meramecian or lowermost Chesterian).

Plate 2. Upper Barnett Shale (Mississippian-upper Chesterian)

1. Upper Faunal Interval- *Gnathodus bilineatus* (late Morphotypes), Nos. 1,2, & 3
2. Upper Faunal Interval- *Lochriea commutata*, No. 4
3. Upper Faunal Interval-*Lochriea monodosus*, No. 5
4. Upper Faunal Interval- *Lochriea nodosus*, No. 6



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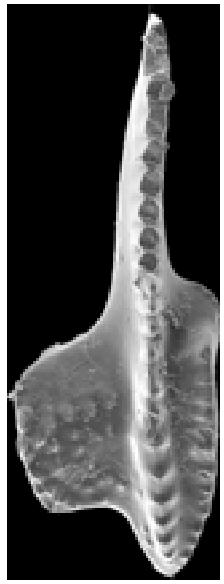

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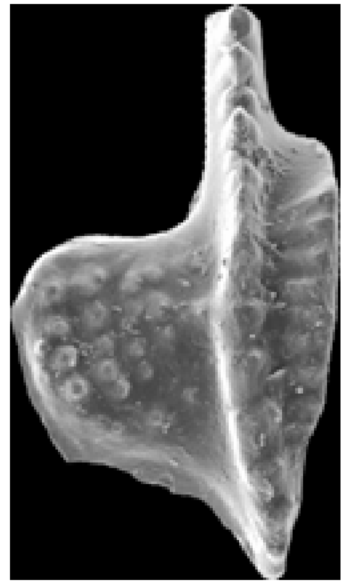

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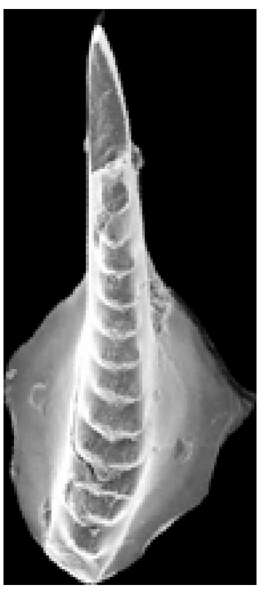

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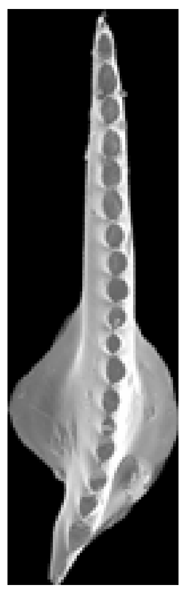

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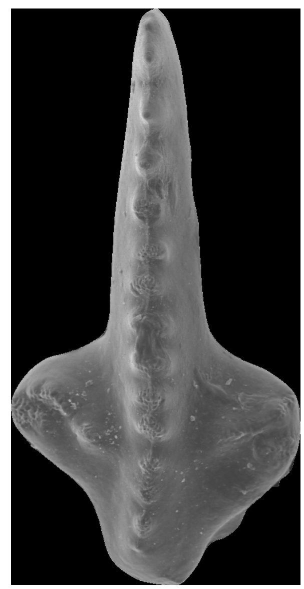

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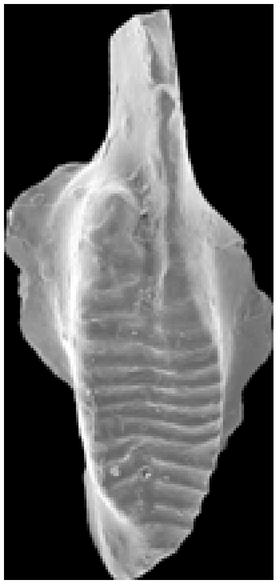
Plate 2. Upper Barnett Shale forms (Mississippian –upper Chesterian).

Plate 3. Upper Barnett (Lower Morrowan)

1. Top Barnett Faunal Interval *Idiognathoides sinuatus*, No. 1

2. Top Barnett Faunal Interval *Neognathodus symmetricus*, No. 2

3. Top Barnett Faunal Interval *Declinognathus* sp., No. 3



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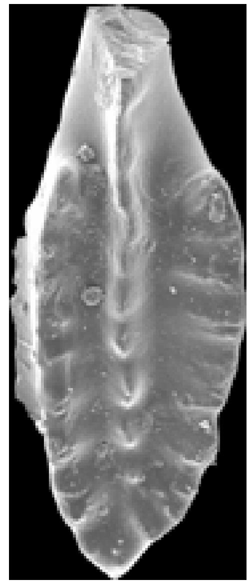

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Plate 3. Upper Barnett Shale forms (Lower Morrowan).

JH MC-1 Well Core

Abundant conodont recovery was observed in the shallow core. The conodonts were identified and analyzed and photographed by Darwin Boardman (2007).

<u>White's Crossing Limestone -upper Osagean, 1107 feet, Plate 4</u>

1. *Bactrognathus communis,* Nos. 1,2 & 3
2. *Gnathodus* sp., Nos. 4,5 & 6
3. *Dollymae* sp., No. 7

<u>White's Crossing Limestone -upper Osagean, 1102 feet, Plate 5</u>

1. *Gnathodus* sp., Nos. 1 & 2
2. *Gnathodus cf. delicates*, No. 3
3. *Polygnathus communis*, No. 4
4. *Bactrognathus communis*, Nos. 5 & 6
5. *Staurognathus* sp., No. 7

<u>White's Crossing Limestone – Meramecian, 1087 feet, Plate 6</u>

1. *Gnathodus texanus,* Nos. 1, 2 & 3
2. *Gnathodus* transitional to *bilineatus*, No. 4
3. *Gnathodus bilineatus* (primitive morphotype), Nos. 5, 6 & 7
4. *Polygnathus cf. communis*, No. 8
5. *Rhachistognathus* n. sp., No. 9

<u>White's Crossing Limestone-Meramecian, 1085 feet, Plate 7</u>

1. *Gnathodus bilineatus* -Primitive Morphotype, No.1

Marble Falls Limestone- Atokan, 1049 feet, Plate 7

1. *Idiognathodus* sp., Nos. 2 & 3

2. *Idiognathoides marginodosus*, No. 4

Plate 4. White's Crossing Limestone -upper Osagean , 1107 feet.

1. *Bactrognathus communis,* Nos.1, 2 & 3

2. *Gnathodus* sp., Nos. 4, 5 & 6

3. *Dollymae* sp., No. 7

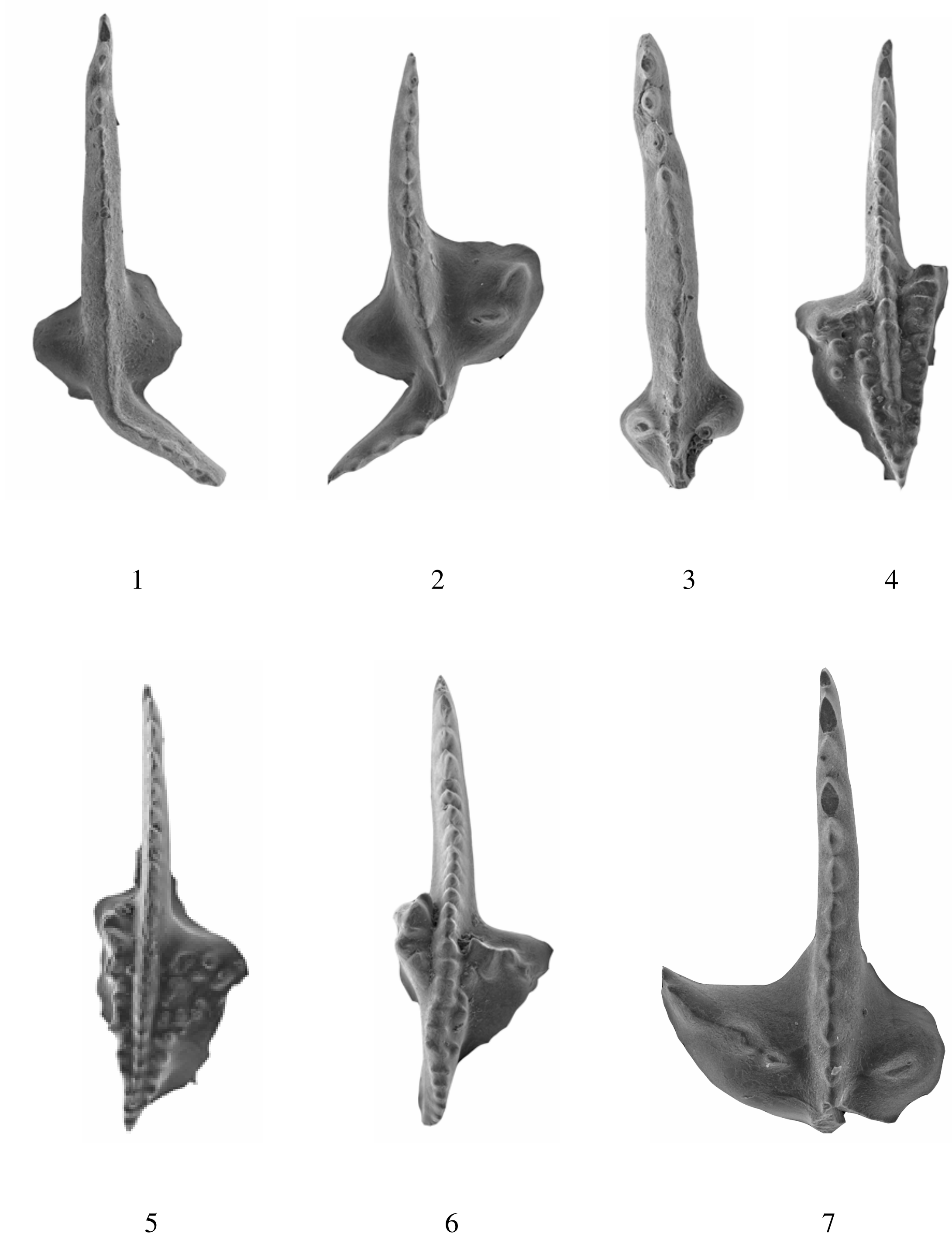

Plate 4. White's Crossing Limestone -upper Osagean, 1107 feet.

Plate 5. White's Crossing Limestone -upper Osagean, 1102 feet.

1. *Gnathodus* sp. Nos. 1 & 2
2. *Gnathodus cf. delicates*, No. 3
3. *Polygnathus communis*, No. 4
4. *Bactrognathus communis,* Nos. 5 & 6
5. *Staurognathus* sp., No. 7

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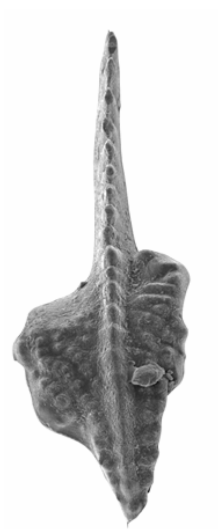

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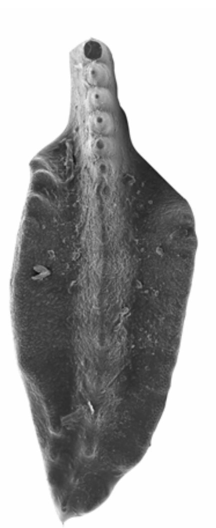

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Plate 5. White’s Crossing Limestone -upper Osagean, 1102 feet.

5

6

7

Plate 5. White’s Crossing Limestone -upper Osagean, 1102 feet (Plate 5 continued).

Plate 6. White’s Crossing Limestone-Meramecian, 1087 feet.

1. *Gnathodus texanus*, Nos. 1, 2 & 3
2. *Gnathodus* transitional to *bilineatus*, No. 4
3. *Gnathodus bilineatus* (primitive morphotype), Nos. 5, 6 & 7
4. *Polygnathus* cf. *communis*, No. 8
5. *Rhachistognathus* n. sp., No. 9

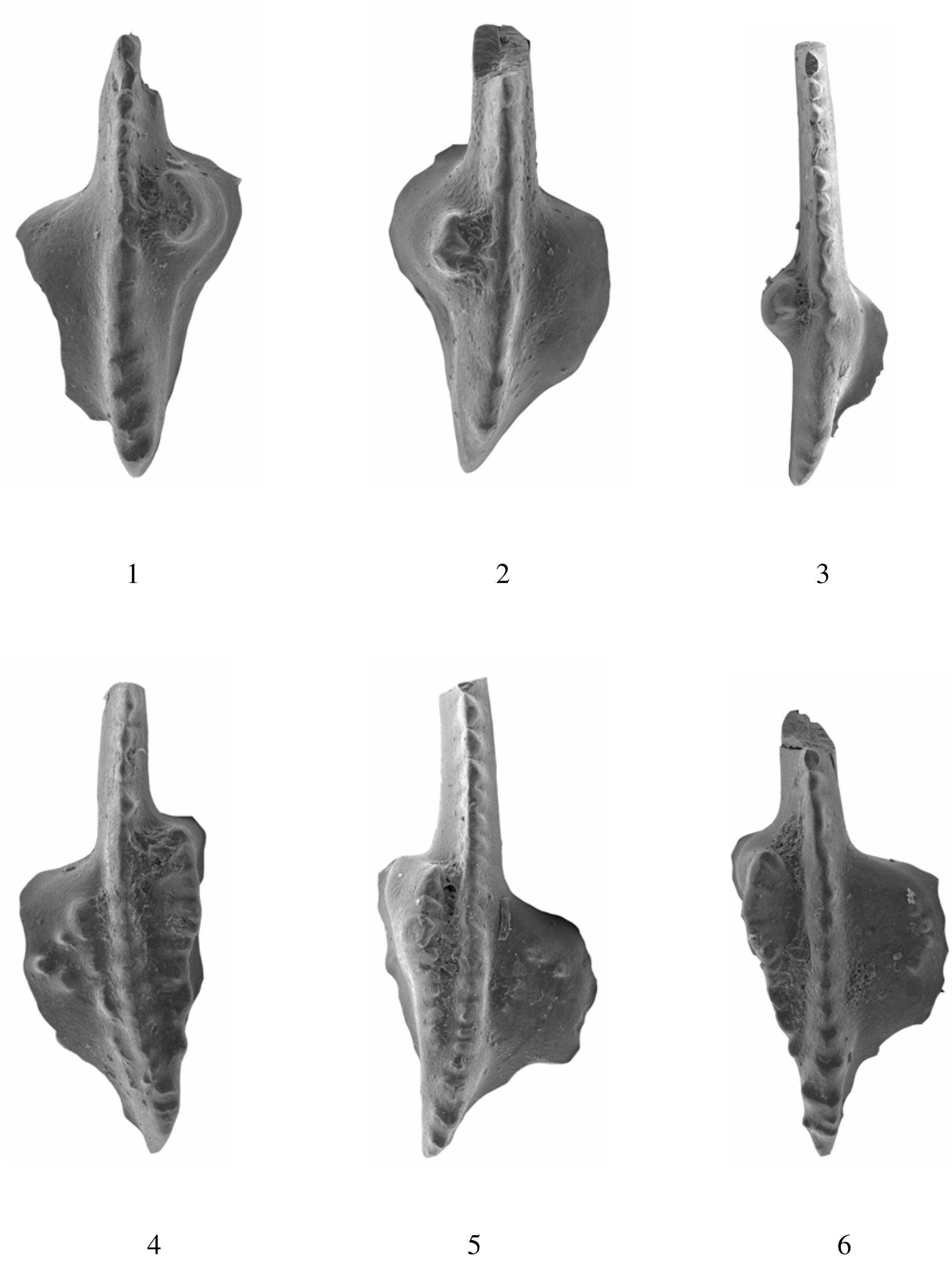

Plate 6. White's Crossing Limestone-Meramecian, 1087 feet.

7 8 9

Plate 6. White's Crossing Limestone-Meramecian, 1087 feet, (Plate 6 continued).

Plate 7. White’s Crossing Limestone- Meramecian, 1085 feet (No.1) & Marble Falls Limestone-Atokan, 1049 feet (Nos.2-4)

1. *Gnathodus bilineatus* -Primitive Morphotype,No. 1
2. *Idiognathodus* sp., Nos. 2 & 3
3. *Idiognathoides marginodosus,* No. 4

1

2

3

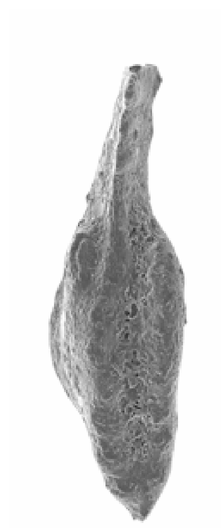

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Plate 7. White's Crossing Limestone- Meramecian, 1085 feet (No.1) & Marble Falls Limestone-Atokan, 1049 feet (Nos. 2-4)

CHAPTER V

CONCLUSION

At type Chappel locality, an apparent complete stratigraphic section of the Barnett Shale is exposed in the combined county road and quarry section. The entire stratigraphic section is fossiliferous and yielded conodonts that were interpreted as follows.

The basal contact of the Barnett Shale and the underlying Chappel at the type Chappel locality is unconformable. This interpretation is supported by faunal analysis (Boardman and Puckette, 2006). The basal Barnett outcrop contains *Gnathodus texanus Gn. bilineatus (sensu latu)* and Cavusgnathus (Boardman, 2006). This conodont assemblage at Type Chappel locality states that the Barnett Shale is latest Meramecian or earliest Chesterian to early Morrowan (Boardman et al., 2007). The unconformity developed on top of the Chappel Limestone is responsible for missing the majority if not all of the Meramecian and the uppermost Osagean at this locality. This unconformity may represent topographic relief as a proto-Bend Arch. There is also a major unconformity separating the top of the Barnett Shale from the Marble Falls Limestone. The top of the Barnett Shale is early, but not basal Morrow at Type Chappel (Boardman et al., 2007). The Barnett at Type Chappel locality outcrop represents a clear pattern of cyclic sedimentation and an apparent shallow upward trend as carbonate increases toward the top of the section.

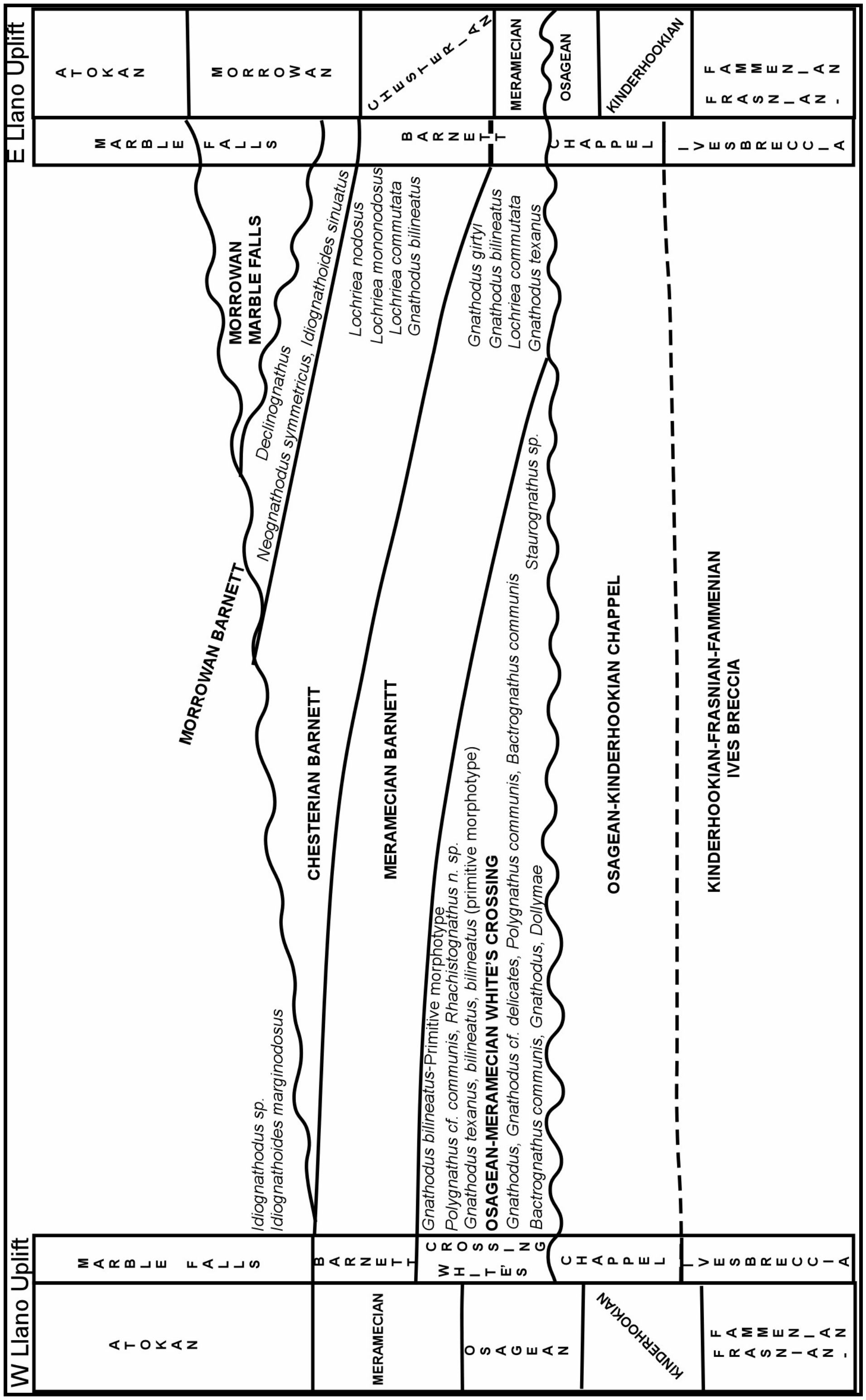

Figure 25. Schematic diagram showing the lithostratigraphic & biostratigraphic correlation of the Barnett Shale-Marble Falls Limestone interval of W Llano Uplift (JH MC-1 core) and E Llano Uplift (Type Chappel locality at San Saba Texas).

The shallow core is located on the western Llano Uplift and contains Chappel Limestone, White's Crossing Limestone, Barnett Shale, Marble Falls Limestone and Smithwick Shale. The Chappel Limestone is unconformably overlain by White's Crossing. The contact between the White's Crossing Limestone and overlying Barnett Shale is gradational. However, there is a sharp contact between the upper Barnett Shale and Marble Falls Limestone. The contact is marked by an exposure surface and represents a period of erosion. The cored Barnett interval is fossiliferous and conodont bearing. It is important to note that conodonts from Chester and lower Morrow are missing from the core. This indicates a significant hiatus in the stratigraphic record. Conodonts recovered from the White's Crossing Coquina indicate it ranges in age from Osagean-Meramecian. The dark Barnett Shale is thin (30 feet) in the core and is Late Meramecian (Boardman et al., 2007). The Chesterian Barnett and Morrowan Marble Falls Limestone at the western Llano Uplift (JH, MC-1 core) is missing due to substantial east to west erosional truncation. This truncation indicates the western Llano Uplift was missing during Morrowan time. The stratigraphic relationship between the western Llano Uplift (Johansen MC-1 Well core) and Type Chappel section is illustrated in Figure 25.

REFERENCES

Arbenz, J. K.,1989, The Ouachita system, in A. W. Bally and A. R. Palmer, eds., The geology of North America—An overview: Geological Society of America, The Geology of North America, v. A, p. 371–396.

Bell, W.C., 1972, Carboniferous history, Llano region, Bureau of Economic Geology, University of Texas at Austin, Guidebook Number 13, p. 38-40.

Bowker, K. A., 2003, Recent developments of the Barnett Shale play, Fort Worth Basin: West Texas Geological Society Bulletin, v. 42, p. 4–11.

Blakey, R., 2005, Paleogeography and geologic evolution of North America; images that track the ancient landscapes of North America: http://jan.ucc.nau.edu/~rcb7/nam.html

Boardman, D., J. Puckette, 2006, Stratigraphy and paleontology of the upper Mississippian Barnett Shale of Texas and the Caney Shale of Southern Oklahoma: Field Trip No. 5, South-Central Section Geological Society of America 2006 Annual Meeting, Norman, Oklahoma: Oklahoma Geological Survey Open- File Report OF 6-2006, p. 86.

Boardman, D. R., J. Puckette, B. Coffey, P. Kamman, N. Aryal, M. Singh, and A. Rihn 2006, Cyclic stratigraphy and conodont biostratigraphy of the Barnett Shale from the type locality of the Chappel Limestone, In: Abstracts with Programs - Geological Society of America, v. 38, Issue 1, p .3.

Boardman, D. R., J. Puckette, B. Coffey, P. Kamman, N. Aryal, M. Singh, and A. Rihn, 2007, Cyclic stratigraphy and conodont biostratigraphy of the Barnett Shale from the type locality of the Chappel Limestone and near-surface cores from the Llano Uplift: AAPG Annual Meeting Abstracts Volume, p. 14.

Burgess, W. J., 1976, Geologic evolution of mid-continent and Gulf Coast areas; plate tectonics view: Gulf Coast Association of Geological Societies Transactions, v. 26, p. 132–143.

Cheney, M.G., 1940, Geology of north central Texas, AAPG Bulletin, v.24, No. 1, p. 65-118.

Cheney, M.G.,1947, Pennsylvanian classification and correlation problems in north-central Texas, Journal of Geology, v. 55, p 202.

Cleaves, A., 1982, Upper Strawn depositional systems of north-central Texas, in C.A. Martin, ed., Petroleum Geology of the Fort Worth Basin and Bend Arch area: Dallas Geological Society, p. 49-95.

Cloud, P.E., and Barnes, V.E., 1946, The Ellenburger Group of Central Texas; The University of Texas Publication No. 4621, Austin, Texas.

Craig, L. C., and C. W. Connor, coordinators, 1979, Paleotectonic investigations of the Mississippian system in the United States: U.S. Geological Survey Professional Paper 1010, p. 371–406.

Cummins, W.F., 1891, Report on the geology of north-western Texas: Texas Geological Survey, 2nd Annual Report, p. 357-552.

Defandorf, 1960, Paleontology and petrography of Carboniferous strata in the Sloan area, San Saba County, Texas: University of Texas, Austin, Master's Thesis, p. 215.

Drake, N.F., (1893), Report on the Colorado coal field of Texas: Texas Geological Survey, 4th Annual Report, p. 355-446.

Flawn, P. T., A. Goldstein Jr., P. B. King, and C. E. Weaver, 1961, The Ouachita system: University of Texas at Austin, Bureau of Economic Geology, Publication 6120, p. 401.

Flippin, J. W., 1982, The stratigraphy, structure, and economic aspects of the Paleozoic strata in Erath County, north central Texas, in C. A. Martin, ed., Petroleum geology of the Fort Worth basin and Bend arch area: Dallas Geological Society, p. 129–155.

Gabb, W.M., 1862, Descriptions of American Tertiary fossils and a new Carboniferous cephalopod from Texas: Academy of Natural Sciences, Philadelphia, Proceedings, p. 367-372.

Girty, G.H., 1912, In Paige, Sidney, U.S. Geological Survey Geology Atlas, Llano-Burnett Folio (no. 183), p. 16.

Girty, G.H., 1911, The fauna of the Moorefield Shale of Arkansas: U.S. Geological Survey Bulletin 439, p. 1-148, pls. 1-15.

Girty, G.H., and Moore, R.C., 1919, Age of the Bend series: AAPG Bulletin, v. 3, p. 418-420.

Grayson, R. C. and G. K. Merrill, eds., 1991, Carboniferous geology and tectonic history of the Southern Fort Worth (Foreland) Basin and Concho Platform, Texas: AAPG, 1991 Annual Convention, Dallas Geological Society Guidebook, Field Trip No. 13, p. 67.

Gutschick, R., and C. Sandberg, 1983, Mississippian continental margins on the conterminous United States, *in* D. J. Stanley and G. T. Moore, The shelf break: Critical interface on continental margins: SEPM Special Publication 33, p. 79–96.

Hass, W. H., 1953, Conodonts of Barnett Formation of Texas: U.S. Geological Survey Professional Paper 243-F, p. 69–94.

Henry, J.D., 1982, Stratigraphy of the Barnett Shale (Mississippian) and associated reefs in the Northern Fort Worth Basin, Dallas Geological Society Bulletin p. 157–178.

Hill, R.T., 1889, A portion of the Geologic story of the Colorado River of Texas. Am. Geol. 3, p. 287.

Hill, R.T., 1901, Geography and geology of the Black and Grand Prairies, Texas: U.S. Geological Survey, 21st Annual Report, pt. 7, p. 666.

HIS Energy, 2003, U.S. production and well history control data bases, Englewood, Colorado.

Jarvie, D. M., R. J. Hill, R. M. Pollastro, D. A. Wavrek, K. A. Bowker, B. L. Claxton, and M. H. Tobey, 2003, Evaluation of unconventional natural gas prospects: The Barnett Shale fractured shale gas model: Poster presented at the 21st International Meeting on Organic Geochemistry, September 8–12, Krakow, Poland.

Jarvie, D.M., R.J. Hill, R.M. Polastro, D.A. Wavrek, K.A. Bowker, B.L. Claxton, and M.H. Tobey, 2004, Assessment of the gas potential and yields from shales: The Barnett Shale model: Unconventional gas of the Southern Mid-Continent Symposium Program and Abstracts, Oklahoma City, Oklahoma.

Johnston, D., January 19, 2004, Technological advances expand potential pay, Oil & Gas Journal, p. 51-52.

Kerans, C., 1988, Karst-controlled reservoir heterogeneity in Ellenburger Group carbonates of west Texas: AAPG Bulletin, v. 72, p. 1160–1183.

Kier, R.S.,1972, Carboniferous stratigraphy of eastern San Saba County and western Lampasas County, Texas PhD. Dissertation, University of Texas at Austin, p. 437.

Kier, R.S., and D.L. Zachry, 1973, Platform carbonates deposition of the lower Marble Falls Formation, central Texas, Joint Session, Midwestern Societies of SEG and Southwest Section, AAPG Abstract, pp. 11-12.

Lahti, V. R., and W. F. Huber, 1982, The Atoka Group (Pennsylvanian) of the Boonsville field area, north-central Texas, in C. A. Martin, ed., Petroleum geology of the Fort Worth basin and Bend arch area: Dallas Geological Society, p. 377 – 400.

Liner, R.T., Walter, L. Manger, Doy L. Zachry,1979, Conodont Evidence For The Mississippian- Pennsylvanian Boundary northeastern Llano Region, central Texas, The Texas Journal of Science, vol. XXXI, No. 4.

Loucks, Robert G., Stephen C. Ruppel, 2007, Mississippian Barnett Shale: Lithofacies and depositional setting of a deep-water shale-gas succession in the Fort Worth Basin, Texas, AAPG Bulletin, v. 91, No. 4 (April 2007), p. 579-601.

Manger, L.W., Sutherland, P.K., Jhonson, D.W., Brown, C.M.,1985, Biostratigraphy of the Mississippian-Pennsylvanian boundary, Llano region, Central Texas, p. 363-365.

Mapel, W. J., R. B. Johnson, G. O. Bachman, and K. L. Varnes, 1979, Southern midcontinent and southern Rocky Mountains region, in L. C. Craig and C. W. Connor, coordinators, Paleotectonic investigations of the Mississippian system in the United States: U. S. Geological Survey Professional Paper, v. P 1010, p. 161–187.

McBee, W. Jr., 1999, Regional paleo-geography and geology of the southern midcontinent, in D. T. Grace and G. D. Hinderlong, eds., The Permian Basin: Providing energy for the future: West Texas Geological Society Publication 99-106, p. 139–158.

McGookey, D. P., 2005, Llano Uplift, In: Abstracts with Programs- AAPG Southwest Section, AAPG Bulletin, v. 89.

Miller, A.K., and Youngquist, W., 1948, The Cephalopod fauna of the Mississippian Barnett Formation of central Texas: Journal of Paleontology, v. 22, p. 649-671.

Montgomery, S. L., 2004, Barnett Shale: A new gas play in the Fort Worth Basin: IHS Energy Petroleum Frontiers, v. 20, no. 1, 74 p.

Montgomery, S.L., D.M. Jarvie, K.A.Bowker, and R.M. Pollastro, 2005, Mississippian Barnett Shale, Fort Worth Basin, north-central Texas: Gas-shale plays with multi-trillion cubic foot potential, AAPG Bulletin, v. 89, No. 2, p 155-175.

Paige, Sidney, 1911, Mineral resources of the Llano- Burnet region, Texas, with an account of the Pre-Cambrian geology: U.S. Geological Survey Bulletin, v. 450, p. 103.

Paige, 1912, Description of the Llano and Burnet quadrangles (Texas): U.S. Geological Survey Geology Atlas, Llano-Burnet Polio 183, p. 16.

Plummer, F.B., and R.C. Moore, 1922, Stratigraphy of the Pennsylvanian formations of north-central Texas: University of Texas Bulletin, 2132, p. 236.

Plummer, F.B., and Scott, G., 1937, Upper Paleozoic ammonites in Texas, in the Geology of Texas, in the geology of Texas: University of Texas Bulletin 3701, v. 3, pt. 1, p. 516.

Plummer, F.B.,1943, The Carboniferous rocks of the Llano Region of central Texas , Bureau of Economic Geology, The University of Texas Publication, No. 4329.

Plummer, F.B., 1945, Stratigraphy of lower Pennsylvanian coral-bearing strata of Texas, Texas University Publication, 4401, p. 63-76.

Plummer, F.B., 1947a, Lower Pennsylvanian strata of the Llano Region- Summary of classification, Journal of Paleontology, v. 21, p.142.

Plummer, F.B., 1947b, Summary of the classification of the Lower Pennsylvanian formations of Texas, with special references to the Lower Pennsylvanian of the Llano region, Journal of Geology, v. 55, p.193.

Plummer, F.B., 1950, The Carboniferous rocks of the Llano Region of Central Texas: Univ. Texas, Publication no. 4329.

Pollastro, R. M., 2003, Geological and production characteristics utilized in assessing the Barnett Shale continuous (unconventional) gas accumulation, Barnett – Paleozoic total petroleum system, Fort Worth basin, Texas: Barnett Shale Symposium, Ellison Miles Geotechnology Institute at Brookhaven College, Dallas, Texas, November 12 – 13, 2003, p. 6.

Pollastro, R. M., R. J. Hill, D. M. Jarvie, and C. Adams, 2004a, Geologic and organic geochemical framework of the Barnett – Paleozoic Total Petroleum System, Bend arch – Fort Worth basin, Texas (abs.): AAPG Annual Meeting Program Abstracts, v. 13, p. A113.

Pollastro, R. M., R. J. Hill, T. A. Ahlbrandt, R. R. Charpentier, T. A. Cook, T. R. Klett, M. E. Henry, and C. J. Schenk, 2004b, Assessment of undiscovered oil and gas resources of the Bend arch – Fort Worth basin province of north-central Texas and southwestern Oklahoma, 2003, U.S. Geological Survey Fact Sheet 2004-3022, p. 2.

Pollastro, Richard M., Daniel M. Jarvie, Ronald J. Hill, Craig W. Adams, 2007, Geologic framework of the Mississippian Barnett Shale, Barnett-Paleozoic total petroleum system, Bend arch Fort Worth Basin, Texas, AAPG Bulletin, V. 91, No. 4 (April 2007), p. 405-436.

Puckette, J., D. Boardman, B. Coffey, E. Gerding, P. Kamman, N. Aryal, M. Singh, A. Rihn, and S. Paxton, (2007), Comparative lithology of the Barnett Shale, Central Texas and age-equivalent Caney Shale in southern Oklahoma: AAPG Annual Meeting Abstracts Volume. P.113.

Roemer, F., 1847, A sketch of the geology of Texas: American Journal of Sciences, serial no. 2, v. 2, p. 358-365.

Roundy, P.V., Part 2, 1926, The micro-fauna, in Roundy, P.V., Girty, G.H., and Goldman, M.I., Mississippian formations of San Saba County, Texas: U.S. Geological Survey Professional paper 146, p. 5-23, pls. 1-4.

Ruppel, S. C., 1985, Stratigraphy and petroleum potential of pre-Pennsylvanian rocks, Palo Duro Basin, Texas Panhandle: University of Texas at Austin Bureau of Economic Geology Report of Investigations 147, p. 81.

Ruppel, S. C., 1989, Summary of Mississippian stratigraphy in north and north-central Texas, in C. E. Mear, C. L. McNulty, and M. E. McNulty, eds., A Symposium on the Petroleum Geology of Mississippian Carbonates in North-Central Texas: Fort Worth Geological Society and Texas Christian University, p. 49−55.

Schmoker, J. W., J. C. Quinn, R. A. Crovelli, V. F. Nuccio, and T. C. Hester, 1996, Production characteristics and resources assessments of the Barnett Shale continuous (unconventional) gas accumulation, Fort Worth basin, Texas: U.S. Geological Survey Open-File Report OF-96-254, p. 20.

Scholle, Peter, A.,1981, A color illustrated guide to carbonate rock constituents, textures, cements, and porosities, AAPG Publication, Memoir 27.

Schwarz, M.E. Bowers, 1975, Cephalopods of the Barnett Formation, Central Texas, The University of Texas at Austin, Master thesis.

Sellards, E.H., W.S. Adkins, and F.B. Plummer, 1933, The geology of Texas, Vol. 1, Texas University Bulletin, 3232, p.1007.

Shumard, B.F., 1863, Descriptions of new Paleozoic fossils: St. Louis Academy of Sciences, Trans., v. 2, p. 108-113.

Sloss, L. L., 1976, Areas and volumes of cratonic sediments, western North America and Eastern Europe: Geology, v. 4, p. 272−276.

Texas Railroad Commission, 2003, Devon Energy Operating Co. Hearing: Docket 'No. 05, 7B, and 09-0235294, July 15, 2003, 55 exhibits.

Thompson, D. M., 1988, Fort Worth basin, in L. L. Sloss, ed., The geology of North America: Geological Society of America, v. D-2, p. 346 – 352.

Turner, N.L., 1970, Carboniferous stratigraphy of western San Saba County, Texas: University of Texas, Austin, Ph.D. diisertation, p. 337.

Turner, G. L., 1957, Paleozoic stratigraphy of the Fort Worth Basin, in Abilene and Fort Worth Geological Societies Joint Field Trip Guidebook: Abilene Geological Society, Fort Worth Geological Society, p. 57 – 77.

Udden, J.A., C.L. Baker., and E. Bose, 1916, Review of the geology of Texas, Texas University, Publication 44, p.178.

Walper, J.L., and Rowett, C.L., 1972, Plate tectonics and the origin of the Caribbean Sea and the Gulf of Mexico: Trans. Gulf Coast Association Geological Society., v.22, p. 105-116.

Walper, J.L., 1982, Plate Tectonic Evolution of the Fort Worth Basin, Dallas Geological Society Bulletin.

APPENDIX

Appendix A, Outcrop data

Lithology description of measured section at Type Chappel, Road Cut section, San Saba, Texas. (Boardman and Puckette, 2006)

Ellenburger Formation Total thickness 2.7 ft

Unit 1 - Cherty Limestone, irregular on top…………………………………………..2.7 ft

Ives Breccia Total thickness ~ 0.7 -1.0 ft

Unit 2- Green shale……………………………………………………………………0.2 ft

Unit 3- Chert Breccia……………………………………………………………….…0.6 ft

Unit 4- Phosphatic limestone………………………………………………………...0.15 ft

Chappel Formation Total thickness 2.0 ft

Unit 5- Limestone, top oxidized zone with solution vugs (exposure surface)………..2.0 ft

Barnett Formation Total thickness ~ 39.4 ft

Unit 6- Grayish green…………………………………………………………………0.4 ft

Unit 7- Reddish brown………………………………………………………………..0.2 ft

Unit 8- Dark yellowish orange- Medium yellowish brown, Unit 8-10……………… 6.6 ft

Unit 9- Nodular limestone & interbedded shale, Unit 10- Dark yellowish orange- Medium yellowish brown

Unit 11- Light bluish gray limestone……………………………………………….0.5 ft

Unit 12- Very pale orange-Pelloidal limestone……………………………………….0.4 ft

Unit 13- Dark yellowish brown……………………………………………………….1.3 ft

Unit 14- Pale yellowish brown………………………………………………………..0.4 ft

Unit 15- Light gray fresh light brown weathered……………………………………..1.3 ft

Unit 16- Pale yellowish brown………………………………………………………..1.2 ft

Unit 17- Medium gray fresh, light brown weathered…………………………………0.5 ft

Unit 18- Dark yellowish brown……………………………………………………….0.6 ft

Unit 19- Light gray fresh, pale yellowish brown weathered…………………………0.5 ft

Unit 20- Pale yellowish brown- Pale yellowish orange………………………………0.4 ft

Unit 21- Light bluish gray…………………………………………………………….0.7 ft

Unit 22- Dark yellowish brown- Moderate yellowish brown………………………...1.0 ft

Unit 23- Dark yellowish orange………………………………………………………0.9 ft

Unit 24- Medium gray………………………………………………………………...3.1 ft

Unit 25- Dark yellowish brown- Moderate yellowish brown………………………...0.8 ft

Unit 26- Pale yellowish brown, possibly juvenile/ embryonic ammonoids, oxidized marcasite………………………………………………………………………………0.6 ft

Unit 27- Pale yellowish brown moderately laminated………………………………..3.9 ft

Unit 28- Pale yellow brown, phosphatic nodules……………………………………..2.0 ft

Unit 29- Thinly bedded limestone upper shaly……………………………………….0.2 ft

Unit 30- Dark yellowish brown- Moderate yellowish brown………………………...0.7 ft

Unit 31- Limestone variable thickness………………………………………0.2 to 0.3 ft

Unit 32- Moderate yellowish brown…………………………………………………..0.5 ft

Unit 33- Medium gray- Medium light gray…………………………………………...1.4 ft

Unit 34- Medium gray- Medium light gray, phosphatic nodules……………………..0.6 ft

Unit 35- Limestone lenticular………………………………………………………0.6 ft

Unit 36- Dark yellowish orange caliche……………………………………………2.0 ft

Unit 37- Massive limestone bed weathers white……………………………………...0.4 ft

Lithology description of measured section at Type Chappel, Quarry section, San Saba, Texas. (Boardman and Puckette, 2006)

<u>Barnett Shale</u>

Unit 1- Medium gray limestone……………………………………………………0.2 ft

Unit 2- Moderately yellowish brown- thin shellved bivalves………………………...0.3 ft

Unit 3- Moderately yellowish brown…………………………………………………1.0 ft

Unit 4- Moderate yellowish orange with lenticular limestone………………………..1.7 ft

Unit 5- Moderate yellowish brown……………………………………………………0.4 ft

Unit 6- Pale yellowish orange………………………………………………………...0.6 ft

Unit 7- Light gray with phosphatic nodules…………………………………………..0.7 ft

Unit 8- Moderate yellowish brown with lenticular limestone………………………...1.5 ft

Unit 9- Grayish orange…………………………………………………………………….2 ft

Unit 10- Light gray limestone- Dark yellowish orange shale………………………...0.2 ft

Unit 11- Medium gray limestone weathers white…………………………………….0.4 ft

Unit 12- Pale yellowish orange shale…………………………………………………0.1 ft

Unit 13- Medium gray limestone with brachiopods…………………………………..0.4 ft

Unit 14- Dark yellowish orange heavy caliche…………………………………………2 ft

Unit 15- Dark yellow brown- Light olive brown glauconitic shale…………………..1.1 ft

Marble Falls Limestone

Unit 16- Light medium gray-cherty……………………………………………..1.2 ft

Appendix B

Core data & Photomicrographs

Detail lithological description from Johansen MC-1 Well core, McCullock, Co. Texas

<u>Type Chappel</u> Total thickness: ~ 4 ft

Unit 1- Fossiliferous poorly consolidated glauconitic crinoidal packstone…………1.35 ft

Unit 2- Yellowish green mudstone………………………………………………..1.12 ft

Unit 3- Oolitic grainstone…………………………………………………………1.35 ft

<u>White's Crossing</u> Total thickness: 42 ft

Unit 4- Reddish gray wackstone/ packstone with crinoids, vugs & pyrite…………...1.8 ft

Unit 5- Marl ………………………………………………………………………..0.9 ft

Unit 6- Crinoidal packstone/ wackstone with underlying scour base ………………5.85 ft
showing soft sediment deformation & flaser bedding

Unit 7- Reddish gray crinoidal wackstone with flaser bedding & styolites…………2.25 ft

Unit 8- Reddish gray mudstone, bioturbated, forms scour with base……………....1.12 ft

Unit 9- Crinoidal grainstone………………………………………………………..1.8 ft

Unit 10- Glauconitic crinoidal packstone……………………………………………2.25 ft

Unit 11- Reddish green crinoidal wackstone with flaser bedding & styolites………2.92 ft

Unit 12- Gray crinoidal grainstone with styolites…………………………………...3.15 ft

Unit 13- Glauconitic packstone/ wackstone with styolites……………………………4.5 ft

Unit 14- Missing section……………………………………………………………...0.9 ft

Unit 15 -Tan gray, glauconitic packstone with styolites……………………………...2.7 ft

Unit 16- Greenish claystone……………………………………………………….1.8 ft

Unit 17- Grayish green grainstone with crinoids & corals…………………………..1.35 ft

Unit 18 - Missing section……………………………………………………………1.35 ft

Barnett Shale Total thickness: 33 ft

Unit 19- Black shale not fissile has bedding plane & shell fragments………………1.35 ft

Unit 20- Grey packstone with crinoids, pyrite filled vugs & shell fragments………...0.9 ft

Unit 21- Calcareous shale black/ green thinly laminated & shell fragments ……….2.25 ft

Unit 22- Wackstone with disarticulated brachiopods, pyritized ....1.12 ft

vugs & flaser bedding

Unit 23- Glauconitic mudstone, dark green to black, debris flow…………………...1.12 ft

Unit 24- Massive siltstone, gray to black, no bedding plane, imbricate……………...4.2 ft

laminated brachiopod shell & burrows

Unit 25- Highly permeable non fissile black shale……………………………………..1 ft

Unit 26- Brittle zone, possibly high silica content ……………………………………..1 ft

Unit 27- Dark shale with high silt content, shell fragment & pyritized vugs…………..1 ft

Unit 28- Black & gray silty shale, calcareous, non fissile, disarticulated………………5 ft

brachiopods along the bedding plane

Unit 29- Green shale/mudstone, poorly consolidated to highly fissile non fossiliferous.5 ft

Unit 30- Green shale, broken pieces, smooth, waxy feel; exposure surface……………5 ft

Marble Falls Limestone   Total thickness: 93 ft

Unit 31- Packstone/ wackstone

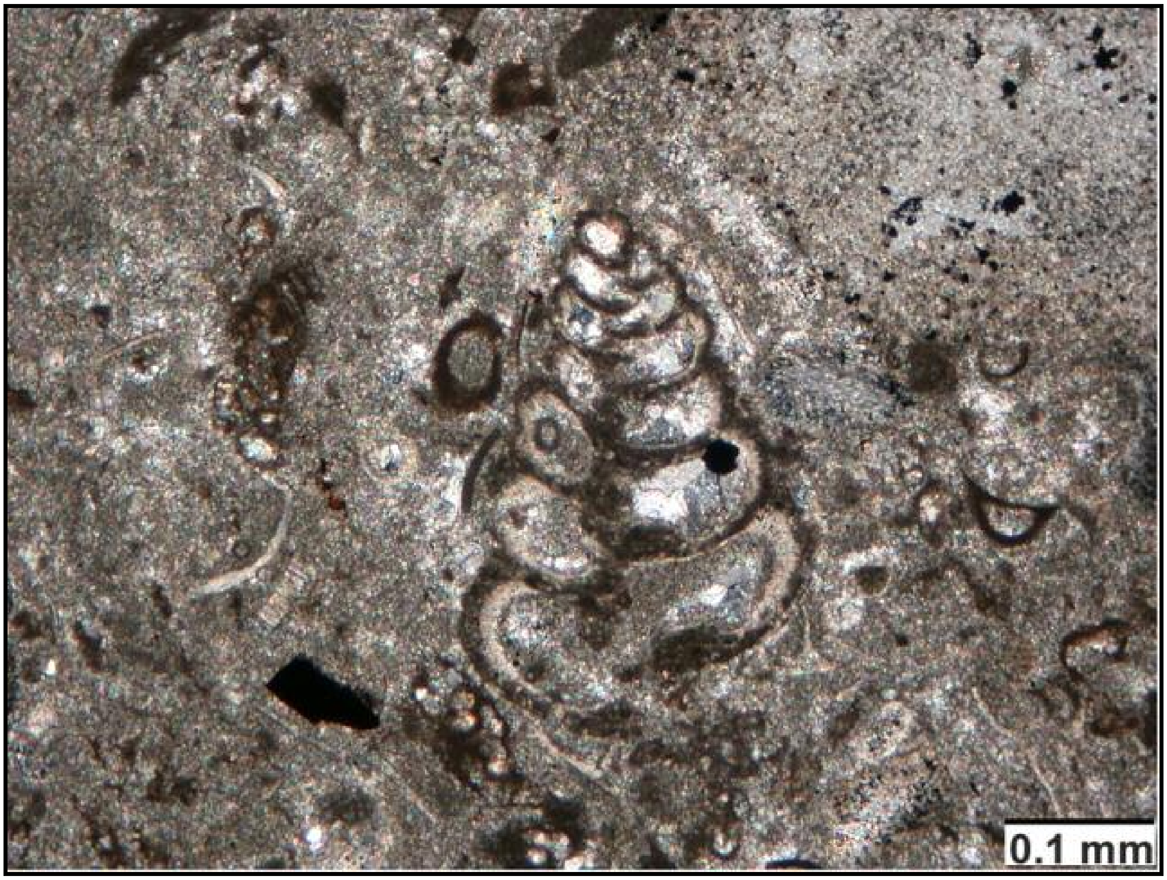

Plate 8. Photomicrograph showing close-up of a uniaxial foraminifer in an uncompacted matrix. Note the micritized wall structures chambers are filled with calcite, JH MC-1, 1055 ft (Marble Falls).

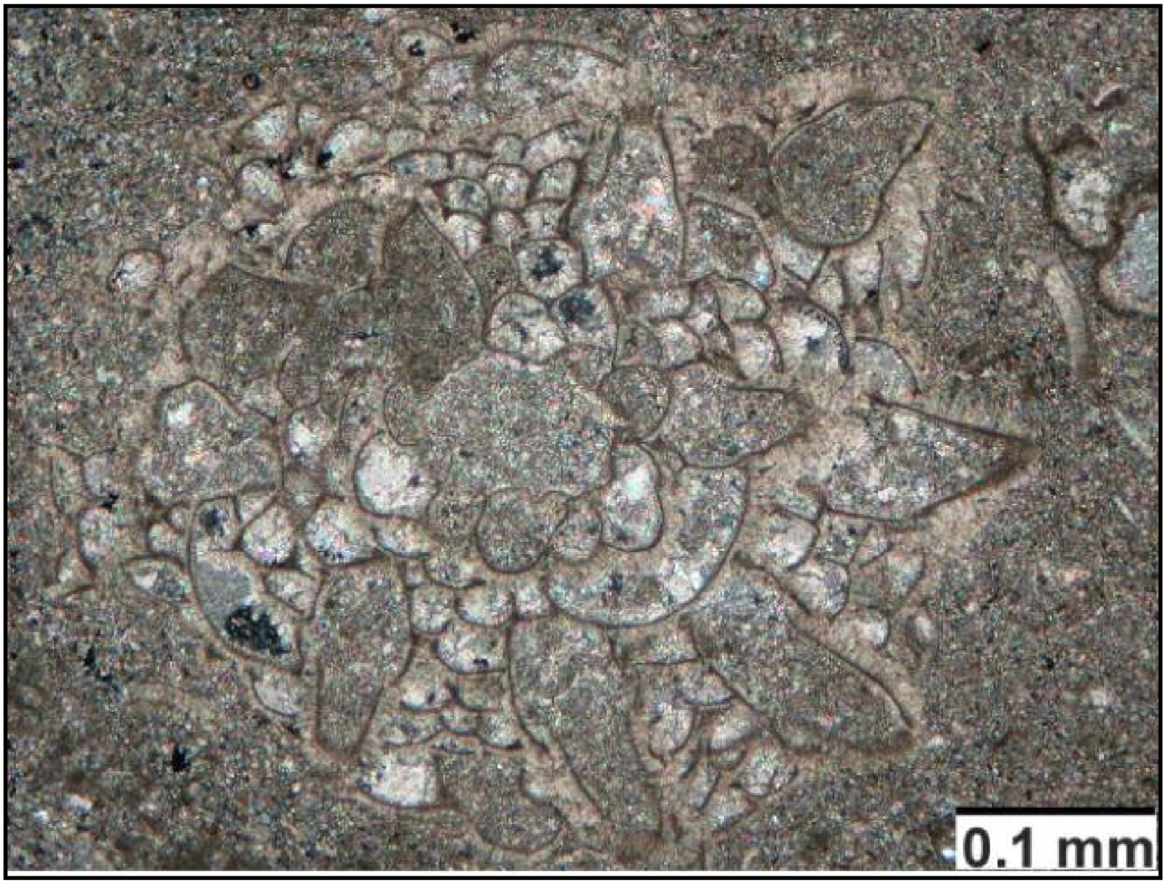

Plate 9. Photo micrograph showing fenestrate bryozoan with fairly regular sub-rounded chambers filled with quartz and sparry calcite cement, JH MC-1, 1055 ft (Marble Falls).

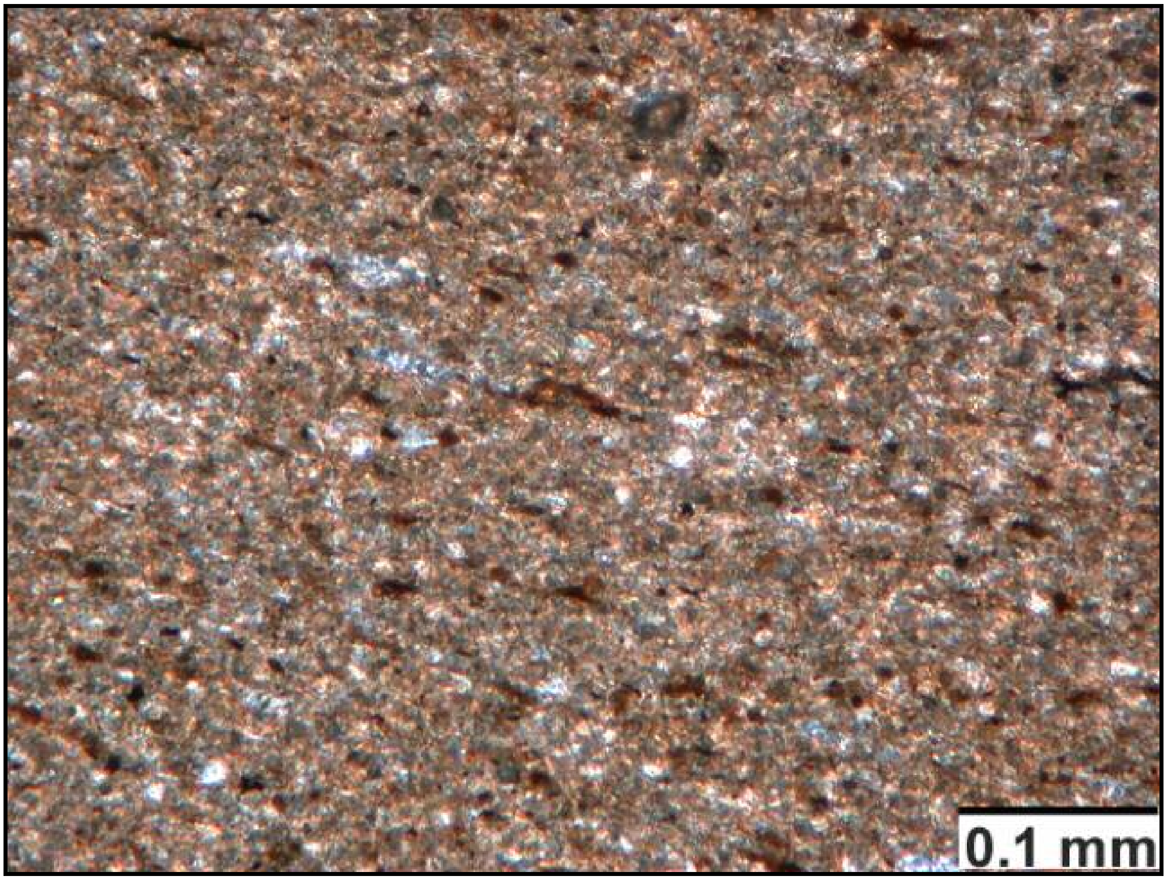

Plate 10. Photomicrograph clotted peloidal texture with detrital silt grains and sparry calcite within Barnett Shale, JH MC-1, 1064 ft.

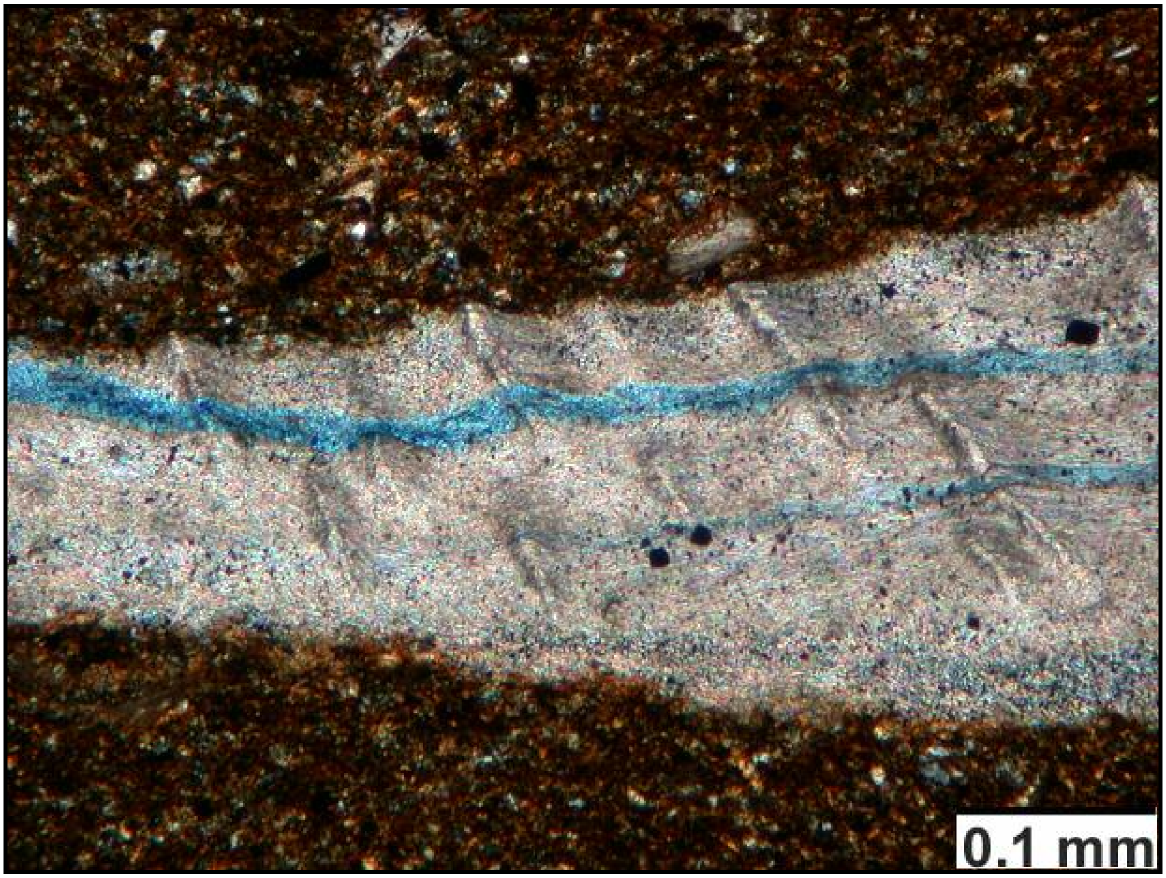

Plate 11. Photomicrograph showing a large brachiopod shell with wavy, parallel laminated shell structure within dark organic rich Barnett Shale JH MC-1, 1067 ft.

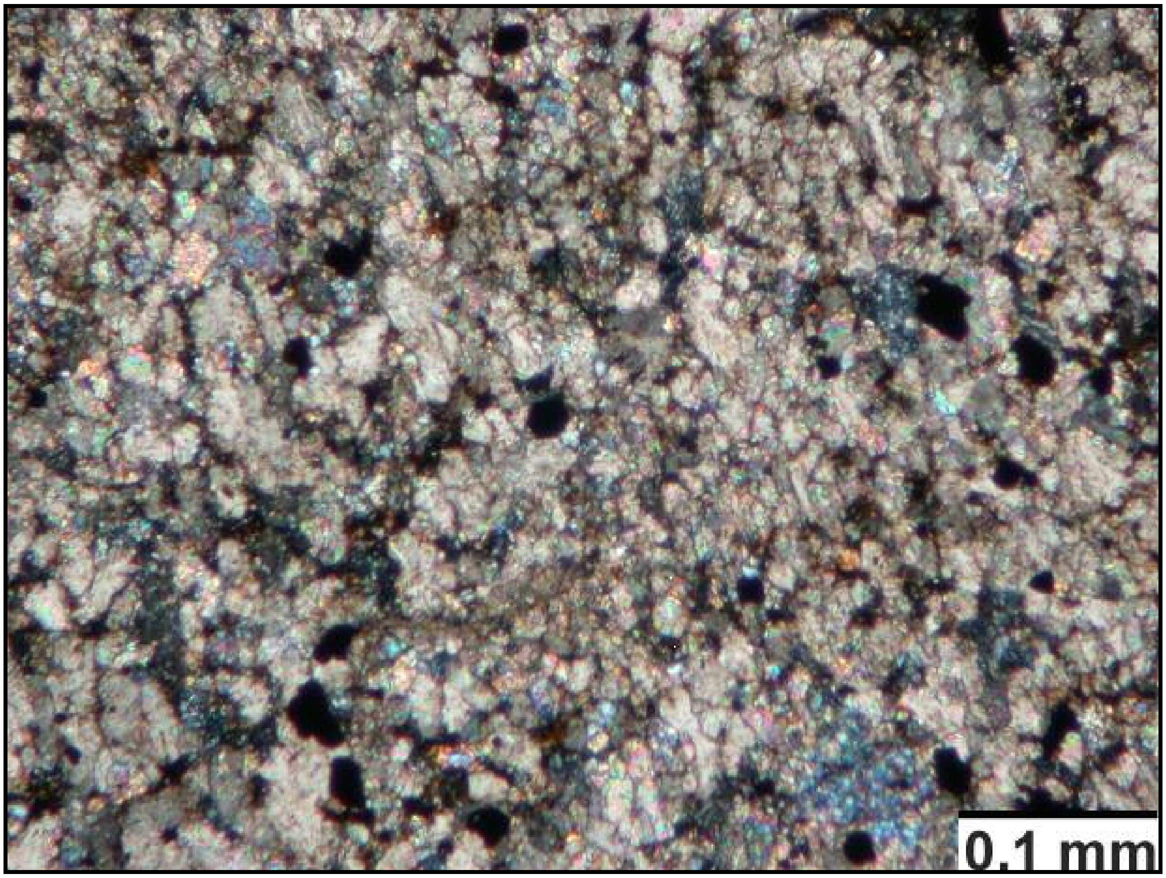

Plate 12. Photomicrograph showing siliceous shale with pyrite (black), in micro-sparry calcite within Barnett, JH MC-1, 1069 ft.

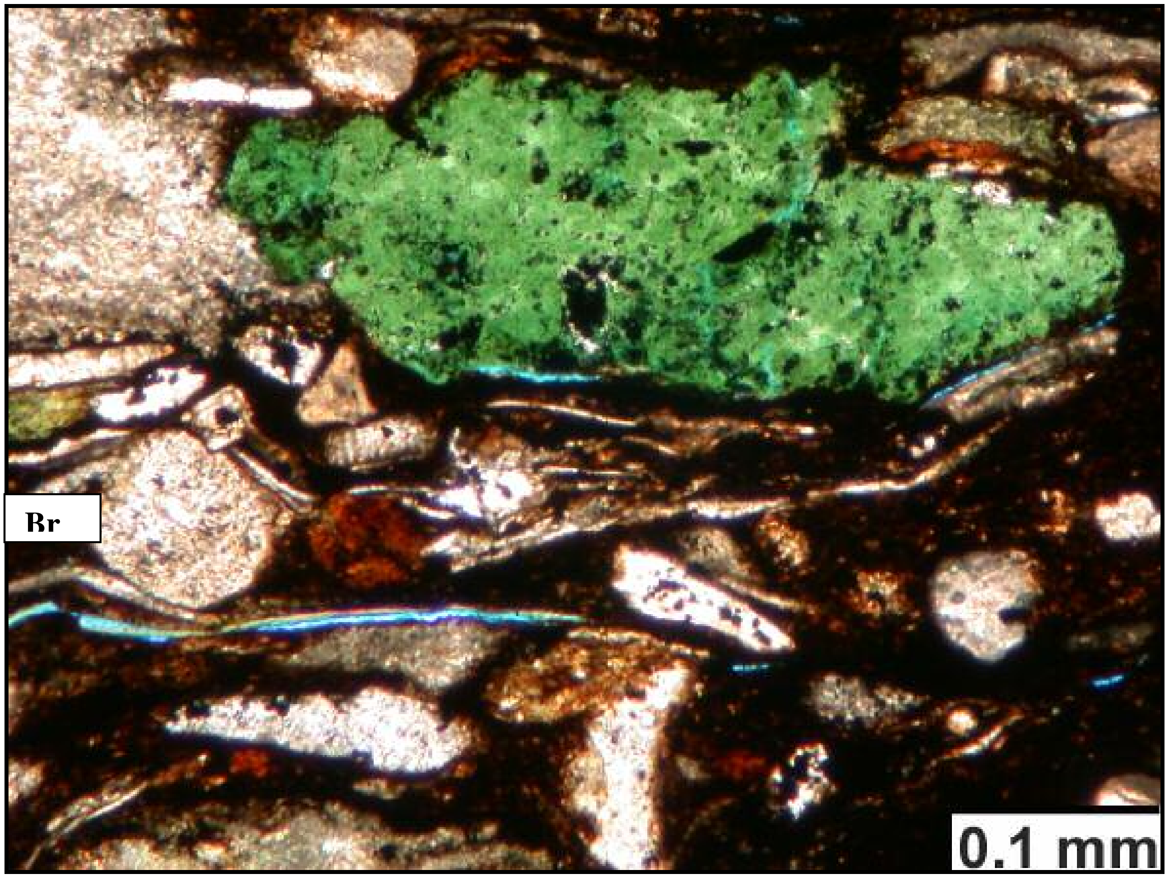

Plate 13. Photomicrograph showing mixture of compacted brachiopod spine (Br), large glauconite grain (green) and pyrite (black) within Barnett, JH MC-1, 1071 ft.

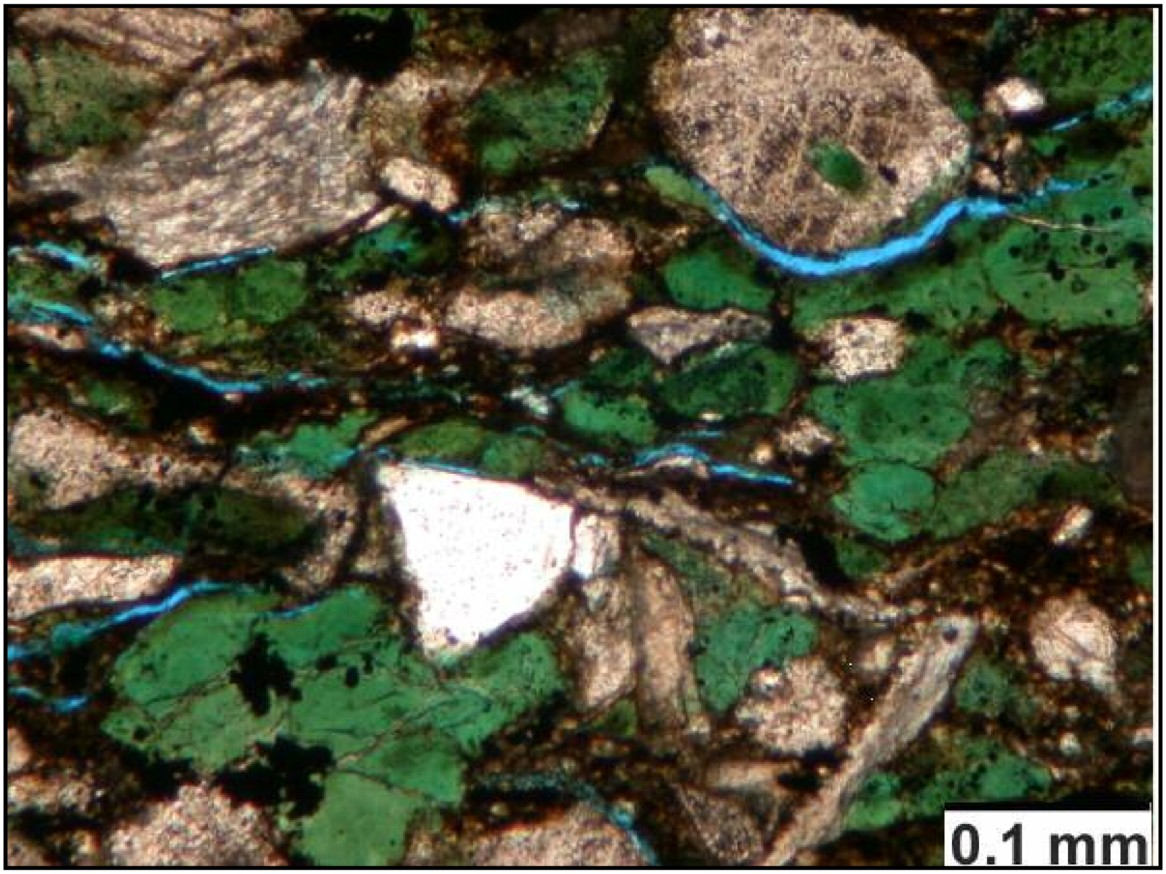

Plate 14. Photomicrograph showing sub-rounded glauconitic (green) grains in glauconitic marl with sparry calcite and pyrite (black) within dark Barnett Shale, JH MC-1, 1083 ft.

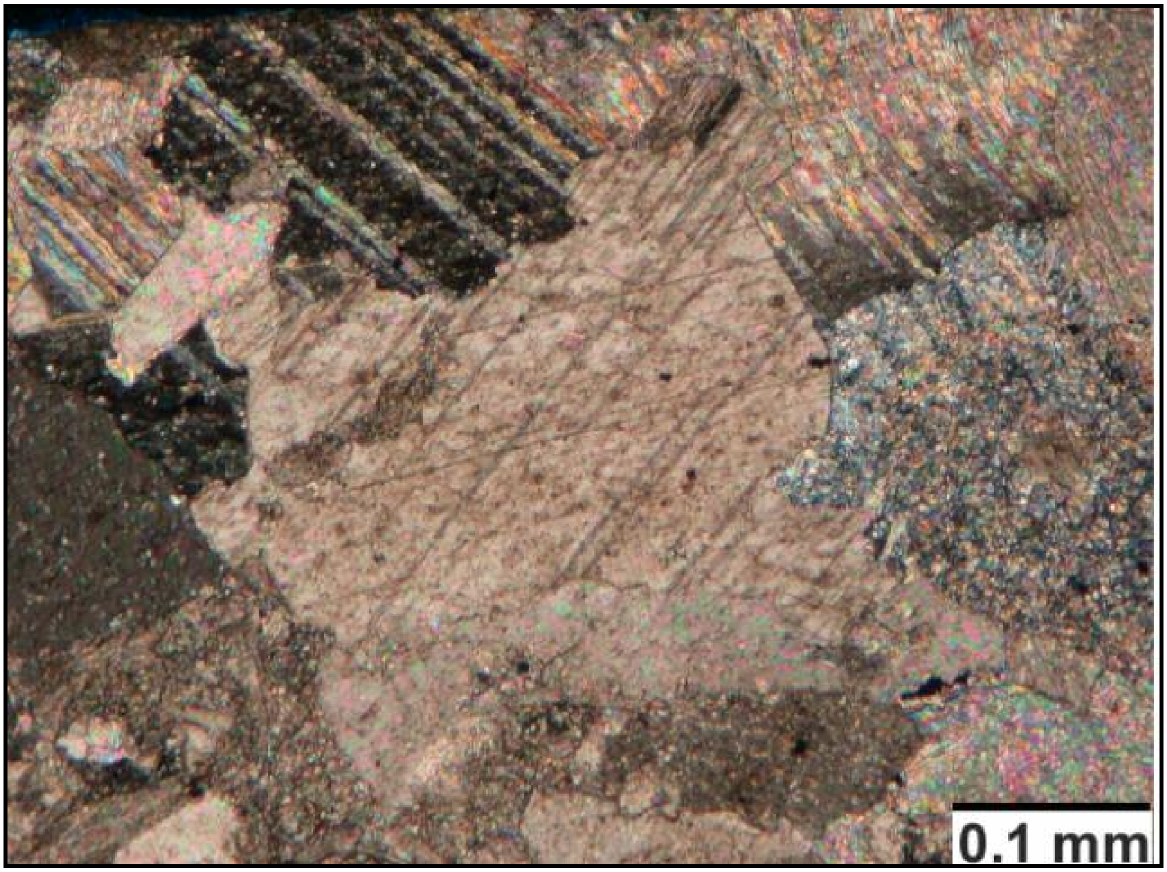

Plate 15. Photomicrograph showing cross hatchet extinction within sparry calcite cement along with chert within White's Crossing Limestone, JH MC-1, 1129 ft.

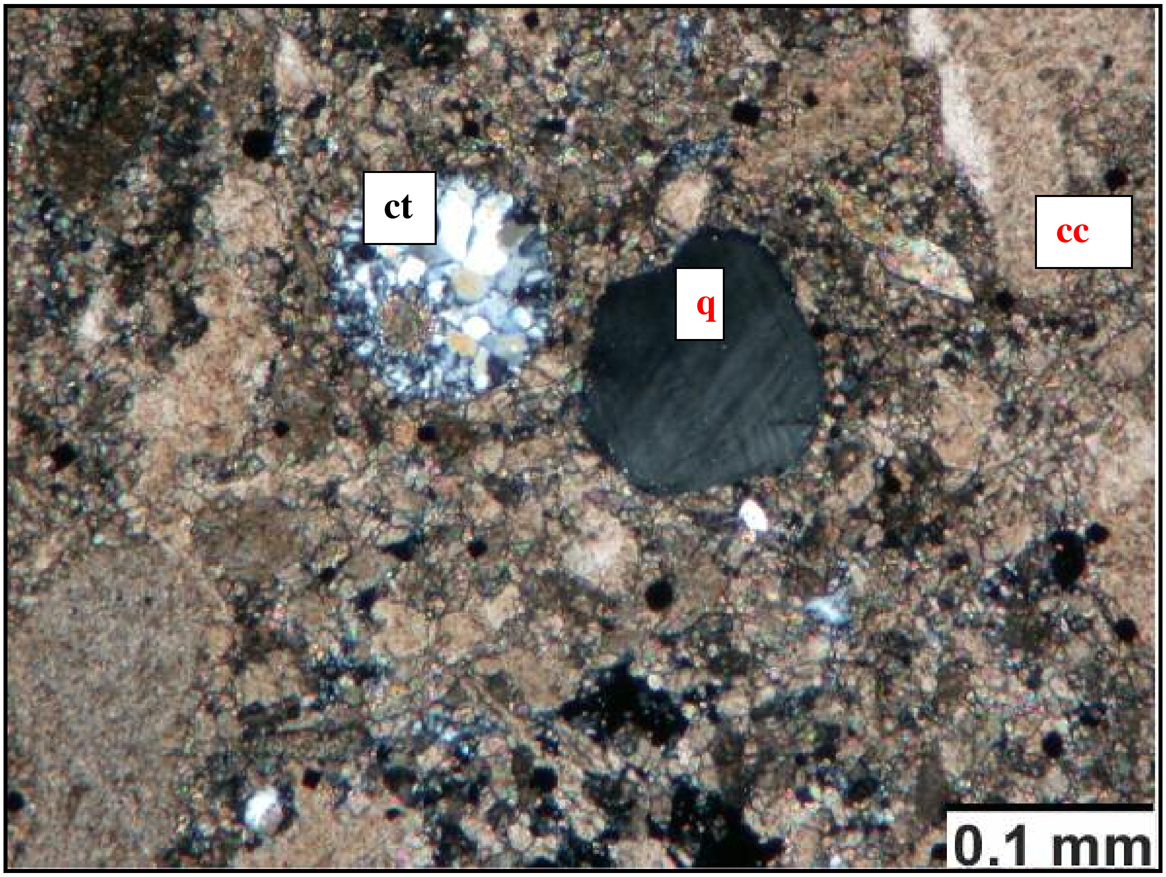

Plate 16. Photomicrograph showing well rounded detrital quartz (q) (at various stage of extinction) sand grains with chert (ct), sparry calcitic cement (cc) within Chappel Limestone, JH MC-1, 1134 ft.

VITA

Manish Kumar Singh

Candidate for the Degree of

Master of Science

Thesis: CORRELATION & BIOSTRATIGRAPHY OF SURFACE AND SHALLOW SUBSURFACE SECTIONS OF THE BARNETT SHALE, LLANO UPLIFT, SOUTH-CENTRAL, TEXAS

Major Field: Geology

Biographical:

Personal Data: Born in New Delhi, India on 6th December, 1979, the son of Mr. R.N. Singh and Mrs. Meena Singh

Education: Graduated from Oak Grove High School, Dehradoon, India, in May 1999; received Bachelor of Science degree in Geology from University of Delhi, Delhi, India, in June, 2003. Completed the requirements for the Master of Science degree with a major in Geology at Oklahoma State University in May, 2007.

Experience: Employed as a Geologist with Data Consulting Services, Schlumberger Limited.

Professional Memberships: American Association of Petroleum Geologists and Oklahoma State University Geological Society.

Name: Manish K. Singh | Date of Degree: July, 2007

Institution: Oklahoma State University | Location: Stillwater, Oklahoma

Title of Study: CORRELATION & BIOSTRATIGRAPHY OF SURFACE AND SHALLOW SUBSURFACE SECTIONS OF THE BARNETT SHALE, LLANO UPLIFT, SOUTH-CENTRAL, TEXAS

Pages in Study: 92 | Candidate for the Degree of Master of Science

Major Field: Geology

Scope and Method of Study:

An outcrop section and a shallow subsurface core of the Barnett Shale from the Llano Uplift, Texas, were described and sampled for conodont biostratigraphy. A total of eighty nine samples were collected and processed for conodont recovery. The biostratigraphic framework was developed based on faunal analysis and correlated to the lithologic descriptions.

Findings and Conclusions:

Exposure surfaces/ unconformities were identified in outcrop and cored section of the Barnett Shale interval. The Barnett Shale in outcrop is missing the middle and lower Meramecian section. The uppermost Barnett Shale contains Morrowan (Pennsylvanian) forms. The Marble Falls Limestone unconformably overlies the Barnett Shale and is missing the lowermost Morrowan section. The cored Barnett Shale interval is missing the entire Chesterian section and is unconformably overlain by Atokan Marble Falls Limestone. The Morrowan Marble Falls Limestone is absent. The contact between the Marble Falls Limestone and Barnett Shale is marked by an exposure surface with an incipient paleosol.

ADVISER'S APPROVAL: ____________________

Dr. Jim Puckette